

University of Newcastle upon Tyne

Department of Education

Ed. D.

*“ The Use of a Thinking Skills Approach to aid the Learning of Difficult
Concepts in Physics Education.”*

Thesis

Michael O'Neill

February, 2003

NEWCASTLE UNIVERSITY LIBRARY

201 29497 9

Thesis V 27

PAGE NUMBERING AS ORIGINAL

BEST COPY AVAILABLE.

VARIABLE PRINT QUALITY

BEST COPY
AVAILABLE.

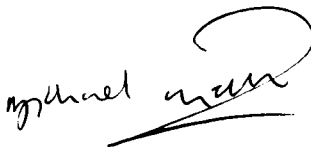
TEXT IN ORIGINAL IS
BOUND INTO THE
SPINE

University of Newcastle upon Tyne

Department of Education

Doctorate in Education

I hereby certify that all material in this submitted work which is not my own has been identified and that no material is included which has been submitted for any other award or qualification.

Signed:  .

Date: february , 2003 .

Contents

1. **Introduction and Overview of Research** (pages 6-11).
2. **Critique of Research Methods** (pages 12-41).
 - Research Methods Employed During the Preliminary Stage.
 - Research Methods Employed During the Main Research Stage.
 - The purpose of the preliminary research.
 - The nature of the data that was collected during the preliminary stage.
 - Table 2.1: Summary of preliminary research areas with sample sizes.
 - Research Methods Employed During the Main Research Stage.
 - The structure of the main research and the methods used to collect the data.
 - Table 2.2: The features of the controlled experimentation that were adopted during the main research period, including sample sizes.
 - The methods used to analyse the data, with reasons to explain why they were used.
 - Standardisation procedures including methods to reduce participant reactivity and experimenter effects.
 - Considerations about the advantages and limitations of the research methods employed.
 - Validity and Reliability.
 - Issues concerning Ethics and Confidentiality.
3. **Preliminary Investigation-Students' Perceptions of Difficult Concepts in Physics** (pages 42-49).
 - Table 3.1: The five areas of the GCSE physics syllabus deemed to be most difficult.
 - Table 3.2: The five areas of the GCSE physics syllabus deemed to be least difficult.
 - The most notable trends obtained from the preliminary research questionnaire.
4. **Difficult Concepts in Physics-a Review of the Literature** (pages 50-99).
 - The nature of memory, working memory and chunking.
 - A Brief History of Short-Term Memory and Working Memory.
 - Figure 4.1: Baddeley's simple representation of the working memory.
 - Figure 4.2: A Cognitive Architecture.
 - The nature of science: macrophenomena, micro level phenomena and symbolic knowledge.
 - Figure 4.3: Johnstone's model of multi-level thought.
 - Table 4.1: Examples of multilevel topics in GCSE physics.
 - Figure 4.4(a) 'before' representation of cocktail problem.
 - Figure 4.4 (b) 'after' representation of cocktail problem.
 - Students' ideas concerning the nature of science.
 - Concrete operational and formal operational thought.
 - Multiple intelligences and multiple solutions.
 - Mathematics.
 - The contribution made by Raw.
 - The contribution made by Kibble.
 - The problem (Kibble, 1999).
 - The contribution made by Gill.
 - Language-based phenomena.
 - Summary of chapter.
5. **Tackling Difficult Concepts in Physics using Thinking Skills Approaches** (pages 100-147).
 - Working memory.
 - Figure 5.1: Dendrogram showing percentage similarity between number strings used in a working memory exercise during the preliminary results episode.
 - Macrophenomena, microphenomena and sub-micro phenomena.
 - Table 5.1: Macro/micro/symbolic composite question examples.
 - Concrete and formal operational thought.
 - Table 5.2: Examples of concrete and formal operational thought thinking stages.
 - Tackling difficult concepts via Raw's work and ideas.
 - Table 5.3: Responses to Raw's questionnaire.
 - Table 5.4: Mean values obtained for Raw's data using my GCSE students.
 - Tackling difficult concepts via Mestre's work and ideas.

Tackling difficult concepts via Georgiades' work and ideas.
 Figure 5.2: The development of scientific conceptions with time.
 Multiple intelligences.
 Mathematics.
 Language.
 Confidence and metacognitive self-regulation.
 How do the areas discussed in this chapter allow difficult concepts to be tackled via a 'Thinking Skills' approach?
 Figure 5.3: Thinking skills design, showing how CASE and non-CASE materials can be used in conjunction with each other to deliver a thinking skills-based programme.

6. **Implementation of Thinking Skills Approaches in the Classroom** (pages 148-162).

The diagnostic stage.
 The main teaching stage.
 Table 6.1: Thinking Skills lessons programme for GCSE groups.
 Table 6.2: Thinking Skills lessons for Year 12 AS level group.
 Table 6.3: Thinking Skills strategies and associated background theory.

7. **Results** (pages 163-222).

Preliminary Results.
 Preliminary working memory data.
 Figure 7.1: Dendrogram to illustrate preliminary and main working memory results.
 Certainty of response and metacognitive self-regulation.
 Table 7.1: Results to show CRI responses for tests taken at GCSE and AS level.
 Mathematics.
 Figure 7.2: Graph to show relationship between physics multiple choice score and maths score for my GCSE students.
 Figure 7.3: Graph to show relationship between performance in an earth and space multiple choice against performance in maths.
 Language and vocabulary.
 Figure 7.4: Graph to show relationship between performance in physics tests and investigative physics practical work.
 Multiple intelligences.
 Summary of main preliminary findings.
 Table 7.2: Piagetian stages of students before the implementation of thinking skills programmes.
 Table 7.3: Test used to diagnose Piagetian stages of development.
 Main Results Section.
 Table 7.4: Comparison between preliminary results and main results involving students' opinions about the easiest and most difficult areas of GCSE physics.
 Main quantitative results with year 11 GCSE groups.
 Table 7.5: Experimental group versus control group for year 11 GCSE physics groups.
 Table 7.6: Effect size and t-test results for year 11 mock GCSE examination data.
 Table 7.7: Perception of difficulty for experimental and control GCSE groups.
 Table 7.8: Perceived difficulty for experimental and control groups at GCSE, 2001.
 Qualitative data responses.
 Main quantitative results with Year 10 GCSE groups.
 Table 7.9: Research carried out with year 10 groups following GCSE physics.
 Table 7.10: Effect size and t-test results for 1999-2000 year 10 control and experimental groups taking separate science GCSE physics.
 Table 7.11: Effect size and t-test results for 1999-2000 year 10 control and experimental groups based on end of 'Electricity' test after delivery of Thinking Skills programme.
 Table 7.12: Responses to thinking skills effectiveness questionnaire.
 Qualitative data responses.
 Main quantitative results with Year 12 AS level group.
 Table 7.13: Perception of difficulty for nine areas of an AS physics module.
 Table 7.14: Responses to thinking skills effective questionnaire from AS students in my institution.
 Qualitative responses.
 What do you understand by the term 'effective' in this study?
 When were the strategies effective, if at all?
 How could the strategies be made more effective?
 Why are some of the strategies better than others?

Who could help make these strategies more effective?
 How do these results have significance in terms of examination performance at GCSE and AS level?
 Table 7.15: Residual scores for experiment group GCSE students based on Yellis data.
 Table 7.16: Residual scores for control group at GCSE based on Yellis data.
 Table 7.17: Residuals for AS level group based on ALIS data.
 Table 7.18: Comparison between modular and linear courses at AS level, based on ALIS data.

8. Summary of Findings and Implications for Further Research (pages 223-232).

9. References (pages 233-241).

10. Appendices (pages 242-358).

- Appendix 1: Questionnaire used to determine the easiest and most difficult areas of the GCSE physics syllabus (p.245-247).
- Appendix 2: Questionnaire used to determine the easiest and most difficult areas of the AS-level physics syllabus (p.248-251).
- Appendix 3: Questionnaire used to determine the easiest and most difficult areas of the legacy A-level physics syllabus (p.252-254).
- Appendix 4: Questionnaire used to determine the areas that are believed to be easiest and most difficult in other subjects, based on the opinions of teachers (p.255-261).
- Appendix 5: Questionnaire used to determine the areas that are believed to be easiest and most difficult in GCSE physics, based on the opinions of physics teachers (p.262-265).
- Appendix 6: Instructions read to students prior to and during working memory data collection episode (p.266-267).
- Appendix 7: Questionnaire used to determine the knowledge and understanding of physics-specific terms, with associated CRI values (p.268-270).
- Appendix 8: Questionnaire used to determine the understanding of vocabulary that can be understood via different physics-specific and mundane definitions (p.271-273).
- Appendix 9: Materials used to determine the extent to which the different multiple intelligences were developed for students involved in the research (p.274-277).
- Appendix 10: Questionnaire to determine opinions concerning Raw's ideas about why students under-perform under examination conditions (p.278-279).
- Appendix 11: Metacognition 'bubble sheets' used during the GCSE and AS level research period (p.280-284).
- Appendix 12: Explanatory sheet for wrestling maths with associated questions (p.285-287).
- Appendix 13: Science reasoning test (SRT) style test (p.288-296).
- Appendix 14: Macro-micro-symbolic style questions (p.297-299).
- Appendix 15: Introductory concept mapping materials (p.300-302).
- Appendix 16: Concept map work produced by student for legacy A level physics syllabus (p.303-304).
- Appendix 17: Examples of P.M.I. style questions used at GCSE and AS level (p.305-307).
- Appendix 18: Introductory pole-bridging material (p.308-309).
- Appendix 19: Introductory key words material (p.310-312).
- Appendix 20: Introductory thinking graphs materials (p.313-315).
- Appendix 21: Introductory mnemonics materials used at GCSE and AS level (p.316-318).
- Appendix 22: Introductory VAKi materials used at GCSE. (p.319-320).
- Appendix 23: Introductory KWL material used at GCSE and AS level (p.321-324).
- Appendix 24: Metacognitive question grids and associated metacognitive material (p.325-330).
- Appendix 25: Exemplar materials produced by students to assist research (p.331-341).
- Appendix 26: Multi-model store representation of human memory (p.342-343).
- Appendix 27: Alternative theories concerning conceptual change learning (p.344-345).
- Appendix 28: Raw data for year 10 groups involved in research with corresponding t-test and effect size statistics (p.346-348).
- Appendix 29: Raw data for year 11 groups involved in research with corresponding t-test and effect size statistics (p.349-353).
- Appendix 30: Table needed for t-test calculations (p.354-355).
- Appendix 31: Standardisation proforma used during year 10 teaching period (p.356-358).

Abstract

This thesis, '*The Use of a Thinking Skills Approach to aid the Learning of Difficult Concepts in Physics Education*', addresses the use and subsequent effect of thinking skills strategies in the teaching and learning of physics at GCSE and A level.

The research has been carried out in three separate stages:

- a) The preliminary research stage;
- b) The implementation stage,
- c) The analysis stage.

In the preliminary research section, students were asked to grade how difficult they thought certain areas of the physics syllabus were in comparison to other areas and they were asked to comment on why they thought that this was the case. As well as trying to determine the most difficult and least difficult areas of the physics syllabus, other information was collected based on the areas of working memory, mathematics, multiple intelligences, language and vocabulary, confidence and metacognitive self-regulation and Piagetian stages of development. The preliminary research stage was also sensitive to the opinions of teachers, lecturers, physicists and other experts and these people also provided some very relevant information. A literature review was conducted and there were two main reasons for this: firstly, to provide further information as to *why* certain areas were seen as being more difficult than other areas and secondly, to help with the construction of a *Thinking Skills* programme which could be delivered to students during the implementation stage of the research.

The year groups involved in the research were year groups 10, 11 and 12 respectively. It was possible to adopt an approach of *controlled experimentation* for the year 10 and 11 groups, with one group in each year group being the *control* group and one group being the *experimental* group. The main research period involved a 7-week thinking skills programme that was administered to the experimental groups but not to the control groups. This was not possible in year 12, so the results obtained from this group had to be compared, on a national basis, with other students of the same age via ALIS data provided by the CEM centre at the University of Durham. The thinking skills that were used are documented thoroughly in this thesis.

The results showed, for years 10 and 11, that the implementation of a thinking skills programme had a very positive effect on the performance of those students that had received the treatment. Statistical methods such as discriminant analysis, t-tests and the effect size were used to show that the experimental group had significantly outperformed the control groups in both year groups. The year 12 data showed that students at AS level had done better than expected compared with students of similar ability by comparing their ALIS residuals.

The results strongly suggest that the thinking skills programme used in this research is a product that could be used to improve the understanding of difficult concepts in physics education at GCSE and AS level throughout the UK.

Chapter One

Introduction and Overview of Research

Ever decreasing numbers of students are taking physics as a subject at AS and A2 level in the UK. Physics has always had a reputation for being a particularly difficult, abstract subject where theoretical and ‘invisible’ concepts such as energy, momentum, charge and permittivity need to be understood and then used in new and unfamiliar contexts. For this reason, physics is deemed to be intangible, aloof and, quite often, uninteresting due to its inaccessibility.

Can anything be done to improve students’ understanding of the subject? Is the delivery of physics in the classroom a problem and do teachers need to address this by looking at their own teaching? Can alternative strategies be used that will motivate students to learn physics and can it be claimed that these alternative methods will actually improve the learning of physics in the classroom? Or, is physics just ‘difficult’ and in no position to be made easier?

In this research, thinking skills strategies were investigated in the physics classroom. The research tried to determine whether a thinking skills approach to the teaching of physics at GCSE and A level had a positive effect on the learning and understanding of physics. Thinking skills materials, especially the ‘Thinking Science’ materials produced by Michael Shayer and Philip Adey as part of the CASE project developed at King’s

College, London are currently very popular with widespread use throughout England and Wales. However, despite being the most popular and ‘famous’ thinking skills resource ‘Thinking Science’ is not the only package that can be used as part of a research-based investigation into the effectiveness of thinking skills materials in the classroom. Other strategies were readily available that had been developed independently and it was deemed to be foolish to have ignored these. These materials were produced by organisations such as CoRT (Cognitive Research Trust), some had been developed by authors, physics teachers, academics and lecturers and I also produced a number of thinking skills strategies myself.

Having collected a number of thinking skills materials together, it was then necessary to construct a teaching timetable in which particular strategies were used in situations where they were seen to be most appropriate. For example, certain thinking skills strategies such as KWL (Know, Want to know, Learned) are suited to the use of video work and these were implemented during lessons where video material was used. Pole-bridging is a technique that is useful within the realm of practical work so this strategy was employed during practical sessions. This work was executed with the extra realisation that over-usage and ‘saturation’ of thinking skills may well have a detrimental effect on learning so only a limited number of thinking skills strategies were used during any given session.

Before there was any construction of the thinking skills programme, a preliminary research period was administered to try and determine which areas of the physics syllabus, at GCSE and A level, were viewed as being most difficult by students at these

stages of their education. As part of this preliminary work, students were asked to comment about *why* they found these particular areas so demanding when compared with others.

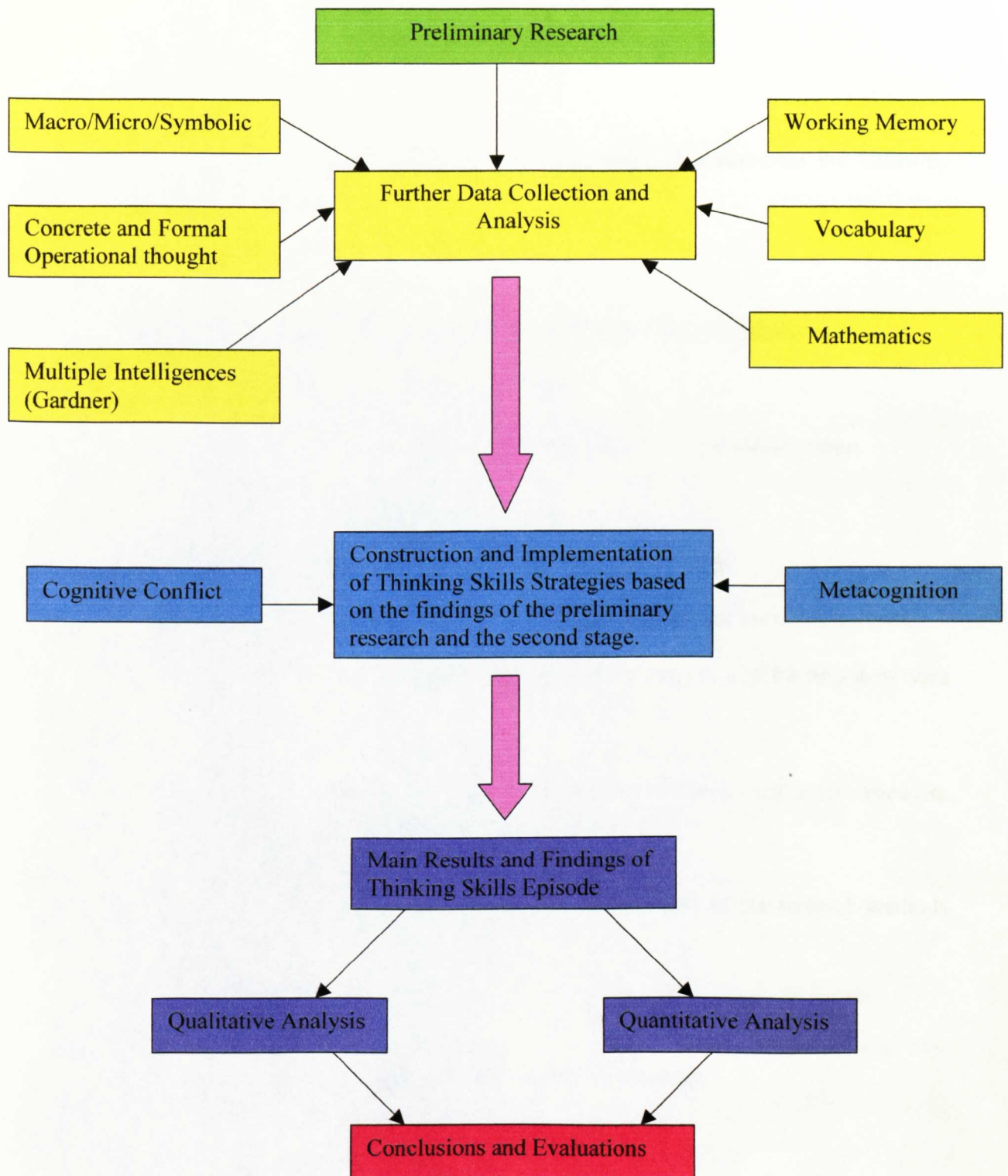
Once the most difficult areas had been identified, along with the reasons, the thinking skills programme was designed to try and combat the problems that had been highlighted. To have controlled experimentation, one GCSE group had the thinking skills treatment and one group was taught via a 'non-thinking skills' curriculum, incorporating no thinking skills techniques. For A level tuition, there were no parallel groups available, so the effects of the thinking skills programme had to be determined via ALIS (A Level Information Service) data, where students in one institution are compared with other A level students nationally to see whether they have made any significant 'improvement'. In addition to this quantitative data, students and teachers were interviewed to add a weight of qualitative material to help support any conclusions. This methodological consideration was included to augment the nature of data collected. This was found to be especially useful when trying to ascertain exactly 'when' and 'where' specific thinking skills strategies should be employed in the delivery of the scheme of work.

Although the main results and conclusions of a research project such as this are concerned with concrete data relating to an improvement in understanding and, hence, examination performance, other factors such as greater enjoyment of the subject and enhanced motivation were also discussed. The four main pillars of the thinking skills

programme, namely preparation, cognitive conflict, metacognition and bridging played a fundamental role in this work.

As an evaluative exercise, the results and conclusions were assessed to provide an insight into the use of such thinking skills techniques. These findings were used to suggest possible improvements in the area of physics and in the education process as a whole.

Research Methodology Structure: Data Collection and Analysis



Chapter Two

Critique of Research Methods

This chapter is concerned with the research method and it addresses the following points:

Research Methods Employed During the Preliminary Research Stage:

- The purpose of the preliminary research.
- The nature of the data that was collected during the preliminary stage.

Research Methods Employed During the Main Research Stage:

- The structure of the main research and the methods used to collect the data.
- The methods used to analyse the data, with reasons to explain why they were used.
- Standardisation procedures including methods to reduce participant reactivity and experimenter effects.
- Considerations about the advantages and limitations of the research methods employed.
- Validity and reliability.
- Ethical issues relating to confidentiality and ontology.

The purpose of the preliminary research

The preliminary research was conducted prior to the main research for the following reasons:

1. To determine whether certain areas of the syllabus are perceived to be more difficult than other areas of the syllabus at GCSE and A level in the opinion of a sample of *students* who had completed these courses.
2. To determine whether *teachers* thought that certain areas of the syllabus at GCSE and A level are more difficult than other areas.
3. To use the information provided by students and teachers, if appropriate, in conjunction with other relevant research material to try and decide *why* these areas are more difficult than others.
4. To construct an appropriate 'Thinking Skills' programme, based on the findings of the preliminary research that could be administered to try and augment learning in certain areas of the GCSE and AS level courses.

It is important to realise that during this preliminary research period, no decisions had been made concerning what the subsequent research methods might consist of, nor what a subsequent 'Thinking Skills' package might look like if, indeed, one was going to be produced at a later date. I was using the preliminary research as an initial diagnostic procedure to try and determine what a sample of GCSE students (N=54) and a sample of physics teachers (N=6) considered to be most difficult and least difficult about the GCSE course. Since I was not looking for any particular pattern to appear in this data (and just relying upon the preliminary stage to act in a purely

diagnostic manner), there was little possibility of any bias being introduced by myself. The questionnaires were simply given out to people and collected in upon their completion. This questionnaire was designed to take no longer than 15 minutes. The GCSE data was collected from year 11 students in my school (N=32) and from year 11 students in a similar Independent school (N=22) with help from a colleague. This colleague was told that the purpose of the questionnaire was to merely collect information and that his students needed to provide *their* responses as they perceived the areas of the syllabus in terms of the difficulties that *they* experienced *individually*. The preliminary data was collected using a questionnaire where students were asked to rate how difficult particular topics were in their opinion. The questionnaire consisted of 36 areas of the GCSE syllabus and students rated their difficulty from 1 to 5, with 1 being 'very easy' and 5 being 'very difficult'. Having provided this discrete quantitative data, students were then asked to choose one topic that they found to be particularly difficult and to explain why, in their own words, they thought that this topic was so difficult. The same was true concerning why students perceived certain topics to be considerably easier than others.

As well as asking students for their opinions about why they found certain topics difficult, the same questionnaire was also circulated to teachers of physics. The intention was to determine whether there was agreement between teachers' perceptions of difficulties in physics and students' perceptions of difficulty in physics. Teachers of other subjects were given a purely qualitative style questionnaire asking for their opinions on which topics in their subjects are generally found to be difficult along with a comment made by staff stating reasons for why they think this is the

case. Teachers of other subjects were also asked to comment on which areas of their subject students found to be easy and they also commented on why they thought that this was the case. A copy of this questionnaire is provided in the appendices. Some of the most important findings from this section of the preliminary research are discussed further in chapter three.

Whilst this preliminary data was being collected, concerning the perceived difficulty of different areas of the GCSE physics syllabus, other data was collected from students concerning other areas that had been provided by the teachers' questionnaires and from research papers. These areas included working memory (N=60), mathematics (N=44), self-confidence (N=96), multiple intelligences (N=100) Piagetian stages of cognitive development (N=44) and the link between written work and investigative work (N=38). The results from these areas will be discussed further in chapter 7.

The nature of the data that was collected during the preliminary stage.

The data that was collected during the preliminary research consisted of discrete, numerical data and qualitative data where data responses were provided in a non-numerical form. A summary of the most significant preliminary research areas is provided on the following page in table 2.1. The decision was made to collect qualitative and quantitative data after a review of some literature involving research methods (Coolican, 1994, Reason and Rowan, 1981, Eysenck, 2000, Fitz-Gibbon and Morris, 1987).

Table 2.1: Summary of preliminary research areas with sample sizes.

	Purpose of data that was collected.	Sample Size and brief description of sample.	Nature of data that was collected.
Difficult Concepts Questionnaires.	To determine if students and teachers thought that certain areas of the GCSE and AS level course were more difficult than others. A separate questionnaire was given to teachers of other subjects to see if there were ranges of difficulty in their subjects.	<i>N=54 (students)</i> <i>N=6 (physics teachers)</i> <i>N=18 (other teachers)</i> 32 of the students that were questioned came from my own institution and they were at the end of their year 11 GCSE course. The remaining 22 students came from a similar independent school and they were also at the end of the same GCSE physics course. The teachers questioned were from my own school and local secondary schools.	The first section of the difficult concepts in physics questionnaire involved the collection of discrete, numerical data. The second section of the questionnaire involved qualitative data being provided on why particular areas of the physics syllabus were deemed to be more difficult than others. Teachers of other subjects provided purely qualitative responses on perceived difficulty in their subjects. Both questionnaires are provided in the appendices.
Working Memory.	To try and determine whether there was a limit to how much information a student could store in the working memory and whether this agreed with work carried out previously by experts in the field of psychology.	<i>N=60 (students)</i> Students (N=44) in years 10 and 11 in my school were given a number of digit strings that they were asked to try and remember and then write down once the instruction to write was given. Students (N=16) in a local school were also used at this stage. These students belonged to year 10.	The data collected was discrete, quantitative data and it consisted of strings of digits that the students had to write down after the teacher had dictated them. Qualitative data was also collected to determine whether students thought that an understanding of working memory could be useful in the delivery and subsequent learning of information.
Confidence (CRI) and self-regulation.	To try and determine what role confidence played in test conditions and to provide an insight into the metacognitive skills that were present in students in my institution.	<i>N=96 (students)</i> 78 students from years 10 and 11 and 18 students from the AS/A level groups were asked questions.	Students were asked to grade how certain they were of choosing the correct answer from a number of multiple-choice tests. They were also asked to decide how important certain areas were when experiencing problems in exams.
Piagetian stages of development.	To determine the range of piagetian levels amongst the students in my school so as to see how many were concrete thinkers and how many were formal learners	<i>N=44 (students)</i> All of the students involved in this study came from years 10 in my own institution.	The students were given standard SRT tasks provided by the 'Thinking Science' pack. Scores on these were converted to Piagetian levels.

Mathematics.	Mathematics scores from the previous year's examination were compared with recent physics scores to see if there was a strong connection between performances in the two subjects. This was done because strategies could then be developed to address problems with the mathematical nature of physics if it was found that it played an important part in the research.	<i>N=44 (students)</i> A sample of students in years 10 and 11 were used. Students were taking both subjects at GCSE. The maths and physics marks used were the previous end of year examination scores.	Quantitative data was collected concerning the students' scores in mathematics and physics examinations. The data was used to find a correlation between performance in the two subjects prior to the thinking skills programme.
Language and vocabulary.	Language and vocabulary were tested via questionnaire to see if there was a link between physics score and language score. Much of the vocabulary was related to physics content and to physics process. This was also used to help determine if there was a link between performance in physics written examinations and physics practical investigations.	<i>N=38 (students)</i> A mixture of students from years 10 to 13 were asked to fill in a questionnaire that would test their knowledge of content-based and process-based physics vocabulary.	The data collected was qualitative in nature but it was encoded into numerical data so that it could be used to find a Pearson correlation coefficient when compared with other scores.
Multiple Intelligences.	To determine if an understanding of multiple intelligence theory would prove to be useful in the learning of difficult physics material at GCSE. If this proved to be true, methods relating to multiple intelligence theory could be used in the thinking skills teaching programme.	<i>N=100 (students)</i> Students in years 10 to 13 were given questionnaires based on Gardner's theory over a two-year period.	Qualitative data was obtained and used purely to determine if multiple intelligences theory was seen to be useful in the learning of difficult concepts. An advantage of this preliminary research is that it led onto Kibble and Tao's ideas of multiple solutions.

The reason why the decision was made to collect quantitative and qualitative data was based on information provided from various 'research methods' texts. The best justification of why qualitative and quantitative methods should be adopted is provided by Reason and Rowan (1981). Firstly, it is important to see their argument for qualitative methods as opposed to quantitative methods:

"There is too much measurement going on. Some things which are numerically precise are not true; and some things which are not numerical are true. Orthodox research produces results which are statistically significant but humanly insignificant; in human enquiry it is much better to be deeply interesting than accurately boring."

Patton (1980, cited in Coolican, 1994) makes another claim about qualitative data:

"The cardinal principle of qualitative analysis is that causal relationships and theoretical statements be clearly emergent from and grounded in the phenomena studied. The theory emerges from the data; it is not imposed on the data."

Whilst I can see the views of the researchers that are mentioned here, it must also be recognised that quantitative analysis is an extremely useful tool. In my personal opinion, it is quite true that qualitative methods can lead to the collection and subsequent manipulation of high quality data that provides a good insight into the behaviour of a particular group. However, it is also true that findings based on

qualitative data are often unreliable and hard to replicate (Eysenck, 2000). For this reason, quantitative methods, in my opinion, should be used in conjunction with qualitative methods. Numerical data is easy to collect and to manipulate and a large volume of numerical data can be collected during a short period of time. Despite not possessing the same 'richness' of information, the argument is that patterns can be deduced from the numerical data using quantitative methods and then the qualitative data can be used to help explain *why* this pattern has emerged. It is very important, in my opinion, to view the use of qualitative and quantitative methods as useful tools to be used together. When used together, the advantages of both methods are available; when used apart, there will be inevitable deficiencies.

During the preliminary research, a number of pieces of research were carried out as mentioned in table 2.1. Of these preliminary investigations, the most important one was the difficult concepts questionnaires, where the aim was to determine if students (and teachers to a lesser extent) believed that certain areas were more difficult than others. It was possible to obtain a large amount of numerical data from a reasonably large initial sample quite quickly. Simple statistical methods, such as the calculation of mean values, could then be performed quite quickly and a pattern could be seen to emerge. However, it would be very foolish to rely on this one single quantitative method as a 'proof' and it is necessary to realise that numerical data and purely quantitative statistical methods of analysis should pay attention to the fact that 'correlation is not causation'. The use of the qualitative methods, where students had to explain why they thought certain areas were more difficult than others, acted to provide extra information that could lead to reasons why these possible relationships

or correlations have occurred. The same argument is used in other areas of the preliminary research where multiple intelligences, confidence and metacognitive self-regulation and the difference between declarative and procedural physics were investigated. Here, numerical and non-numerical data were collected. In certain areas, where it was difficult or unnecessary to collect non-numerical data, only purely quantitative methods were adopted. The reason why qualitative data was not used in determining a relationship between mathematics performance and physics performance was because I was using data that was one year old and so I did not wish to question students on material that they might no longer be familiar with. I was also, at this stage, only interested in looking for a relationship between mathematics scores and physics scores and not particularly interested in the perceived reasons for these.

Research Methods Employed During The Main Research Stage.

The structure of the main research and the methods used to collect the data.

The preliminary research was conducted to determine whether the subsequent research concerning whether a thinking skills approach could aid the learning of difficult concepts in physics education. Once I was satisfied that students could benefit from such a programme, the main thinking skills package was developed. This stage of the research was conducted via *controlled experimentation* for the two GCSE groups in years 10 and 11, whereas the AS level programme was delivered to a single group during their first AS level module and their results were *compared with other students nationally* using data provided by the ALIS (A Level Information Service) based at Durham University.

For both the GCSE and AS level courses, a 7-week ‘thinking skills’ package was developed based on the findings from the preliminary research data and the initial literature review. One group in year 10 received the thinking skills based package and they were referred to as the experimental group. The other group in year 10 was taught via a ‘conventional’ method with no thinking skills activities being administered. The same method was used in year 11, with one class being used as the experimental group and the other class being used as the control group. Both year 10 and year 11 students were studying the topic of ‘Electricity and Magnetism’ and the thinking skills package was based on this area.

Since there is only one AS level group in my school, the AS level thinking skills package was delivered to all of the members of year 12 and their results were

compared with other students, nationally, using the aforementioned ALIS data provided by Durham University.

The most important features of the main research period are summarised in table 2.2.

Table 2.2: The features of the controlled experimentation that were adopted during the main research period including sample sizes.

	Control Group	Experimental Group	Preparation Features
Year 10 and 11 Groups.	The control group was taught in a conventional manner without any exposure to thinking skills. This involved a 7-week period involving bookwork, dictation, standard practical and investigatory work, use of CD ROM and internet facilities and standard homework activities involving the answering of appropriate questions and the completion of appropriate classnotes. <i>N=22 (Year 10)</i> <i>N=23 (Year 11).</i>	The experimental groups in years 10 and 11 were taught via a thinking skills package involving a number of thinking skills that tended to lend themselves to particular learning situations. The actual thinking skills programme is referred to in much greater detail in chapter 5. Table 5.1 summarises how the thinking skills programme was delivered over the seven-week period. <i>N=16 (Year 10)</i> <i>N=23 (Year 11).</i>	It was necessary to ensure that all groups were given access to the material specified in the AQA Physics GCSE syllabus despite the differences in access to the thinking skills. The classes in year 11 were both taught by myself so teacher standardisation was relatively easy. Different teachers were involved in the teaching of classes in year 10, so standardisation issues needed to be addressed in this particular case. Discriminant analysis was used to compare the groups before the main research period started.
Year 12 Group	There was no internal control group available for this group of students.	The experimental group was given a 7-week course based on their first AS level module entitled 'Particles, Waves and Quantum Phenomena'. This group's modular results would be compared with other students, nationally, using a regression equation and residuals. <i>N=14 (students)</i>	Once the thinking skills package had been developed, it was delivered to all students in the group. No teacher standardisation issues needed to be addressed as no control group was involved. As previously stated, analysis would be via a regression equation developed by academics at Durham University.

The data collection methods are discussed below:

a) Questionnaire. Students and teachers, when questioned, were asked to fill in a purely quantitative section of the questionnaire, but they were also asked to comment on their responses via the written word. The purpose was to help 'elaborate' upon the numerical answers given in a questionnaire intended for quantitative analysis. For example, students were asked to grade a particular area of a GCSE physics topic from 1 to 5, with 1 representing 'minimal difficulty' and 5 representing 'maximum difficulty'. Two students might both have given responses of 4 for the same topic, but unless further probing was implemented, the reasons behind why they found these areas so hard may not be apparent. Evidently, both students might experience the same problem with an area for the same reason, such as a difficulty with the mathematics, but the other possibility, and this is possibility very significant, is that two separate students might experience similar levels of difficulty in the same area of the syllabus for two completely different reasons. The need for qualitative data was helpful here for establishing good inter-rater reliability. Student one might have found the mathematics difficult, whereas student two might have found that it was the vocabulary and language involved in the area that caused the problems and not the mathematics. This, obviously, could not be determined from a purely numerical style questionnaire, neither could it be determined easily by a purely quantitative statistical method.

b) Interview. In order to determine exactly what the difficulties are with a particular physics topic, the most direct and accurate way to determine this is via interview:

simply asking the students which topics they found most difficult and why this was the case. The major advantage of this is that the interview technique, if open-ended, would allow students to explain in as much detail exactly what their particular problems are. The main disadvantage is that this technique requires a large amount of time to conduct the interviews, to collect the data, and then an even greater amount of time to analyse the data.

Internal interviews involving my own students and colleagues were conducted via question and answer sessions where myself and the other individual discussed a number of issues relating to the difficulties experienced by students that had been highlighted from the preliminary research. Interviews were conducted by selecting a random sample of students from different classes and year groups and the 'one to one' interview structure was used, to avoid corruption of data and to avoid bias.

Individual responses to questions, although more time consuming, are better, in my opinion, because the data is coming from one subject and not a number of subjects where one member of the group could dominate and not allow other equally valid opinions to be expressed. The 'one to one' approach also allowed the research to be more 'private' and increases the level of confidentiality promised to subjects by removing subjects who could possibly have ruined the confidentiality in the research by being indiscreet.

c) Audiotape. Internal interviews are relatively easy to conduct and the data is easy to gather. The standardisation process of interview length, questions, interaction between interviewer and interviewee and setting can all be determined before the session to maximise ontological objectivity. On no occasions was data collected from

groups of students as this, in my opinion, could have caused the nature of the discussion to 'diverge' and have become less focussed.

The methods used to analyse the data, with reasons to explain why they were used.

The nature of the data that was collected was numerical and non-numerical in nature so quantitative and qualitative methods for analysis were available. Having decided that both quantitative and qualitative techniques would be used, it was then necessary to explain which particular analysis techniques would be adopted. There were a number of statistical techniques that could have been utilised, but some were more suitable than others. It was also important not to choose a very powerful and sophisticated statistical tool to analyse data when a much more straightforward technique could do the same analysis much more easily. The quantitative techniques that were used, along with the reasoning behind the choices, are listed below:

a) Pearson correlation: Pearson's correlation is a statistical tool that compares an independent variable with a dependent variable. As an example, it may be necessary to compare a student's performance in one type of test with performance in another, very different, test. The Pearson's correlation can show whether there is a positive or negative correlation between the two variables, or whether there is no correlation at all. Pearson correlation is useful provided it is used in conjunction with another statistical method such as a t-test.

b) Cluster analysis: Cluster analysis allows groups of data to be compared in groups or clusters which are then compared with other groups, the result being a convergent series of clusters showing their degree of similarity. This method is useful for comparing data where stark degrees of similarity or difference could be significant. In particular, cluster analysis is useful when the clusters are represented as dendrograms. The cluster analysis technique was adopted when viewing the working memory data during the main and preliminary research stages.

c) Discriminant analysis: This was used to decide whether a random result chosen from a test can be placed into one group or another based on the probability that it belongs there. Discriminant analysis was used before the main research stage to determine how similar the control and experimental groups were in years 10 and 11. This was done to see whether a student chosen at random could be shown to have more chance belonging to one group than to another group, based on previous performance. For the year 11 students, it was shown that there was equal chance of a student, chosen at random, belonging to either group. This suggested that the groups were 'equally matched' based on their average previous performance in physics examinations. Hence, any improvement in the experimental group could, in part, be attributed to the thinking skills package. For the year 10 groups, discriminant analysis showed that the experimental group was 'better' than the control group by an average of 6%. This would have to be taken into consideration when the data was being analysed at the end of the research period.

d) The t-test and effect size: The t-test is a very useful quantitative technique which can be used to determine whether there is a statistically significant difference between

the mean scores of the control and experimental groups (Fitz-Gibbon, 1987). Although discriminant analysis is very useful for determining the similarity or difference in the structure of the control and experimental groups it is the t-test that actually allows the investigator to determine whether these differences are significant. The t-test involves the calculation of a t-value using the equation:

$$t = [(d) (\sqrt{n})] / s_d$$

where: 't' is the t-value, 'd' is the mean of the set of differences, 'n' is the number of pairs involved in the matched t-test and 's_d' is the pooled standard deviation.

If the t-value obtained is greater than the tabled t-value then the difference between the means of the experimental and control groups is statistically significant. A table of t-values is provided in the appendices.

Once the mean difference between the groups has been found a value called 'the effect size' can then be calculated. The effect size is determined by dividing the mean difference between the two groups by the pooled standard deviation. The effect size is calculated using the equation:

$$ES = (Y_E - Y_C) / s_d$$

Where: 'ES' is the effect size, 'Y_E' is the mean score of the experimental group, 'Y_C' is the mean score of the control group and s_d is the pooled standard deviation.

A value of 1.00 for the effect size would imply that the experimental group's distribution had been shifted to the right by one standard deviation. A value of 0.8 is often regarded as being large enough to suggest that there has been a significant improvement of the experimental group in comparison to the control group. A value for the effect size of less than 0.4 is not particularly large and, despite showing an increase, does not tend to suggest that the level of improvement is particularly 'exciting'.

Standardisation procedures including methods to reduce participant reactivity and experimenter effects.

When designing an investigation of this nature, certain measures need to be considered so that the results that are obtained have not been corrupted by experimenter effects. It was necessary to ensure that the experimenter was aware of his behaviour at all times during the main research period. This did not pose a problem for the two groups in year 11, since they were both being taught by one teacher, i.e. myself. However, it was necessary to ensure that strategies were employed in the year 10 situation, since I was teaching the experimental group and a colleague was teaching the control group. In order to reduce these potential problems with 'experimenter effects' it was decided that the two experimenters needed to meet

once each week, prior to the teaching episode. During these meetings the following areas were addressed:

1. The experimenters discussed potential problems that might affect the research and corrupt any data collected at a later date. A proforma was produced where instructions, behaviour, teaching strategies and learning outcomes were recorded with measures for standardisation to be included. An example of such a proforma is included in the appendices.
2. The resources available to each group were kept the same apart from any resources involving thinking skills that were only available to the experimental group. This was easy to standardise since the school's only dedicated physics laboratory was used during all lessons in this research period. By coincidence, these lessons also took place at exactly the same time of the day, reducing other contaminating effects such as 'tiredness'.
3. Measures were taken to ensure that 'experimenter fudging effect', 'experimenter misrecording effect', 'experimenter personal attributes effect' and 'experimenter failure to follow the procedure effect' were minimised. These were discussed during our meetings prior to the teaching sessions. It was stressed that issues of 'ontological objectivity' were adhered to at all times. Students were treated exactly the same, where possible, and pre-determined procedures were followed very strictly. All results that were recorded were never altered, regardless of experimenter expectation.

Lessons were observed on three occasions to ensure that these procedures were being followed as closely as possible.

4. Students were not informed of what we were trying to do; the research procedure was 'single blind' which means that the students were not aware of the conditions in which they had been placed, but we, as experimenters, were. Students were not deceived; they were just not informed of the research since 'participant reactivity' could have severely corrupted the data. If the groups had become aware that controlled experimentation was taking place then they might have adapted their behaviour to try and influence the outcome. Participant reactivity such as 'The Hawthorne Effect' (Roethlisberger and Dickson, 1939) needed to be considered and then removed.

Considerations about the advantages and limitations of the research methods employed.

There are advantages and disadvantages associated with all of the data collection and analysis techniques used when performing research. These problems arise because of the technique itself or because of the context in which it is being used. The relative merits and problems associated are listed below/overleaf.

Questionnaires: Questionnaires can be very useful because a large volume of data can be collected quickly for simple quantitative analysis via a statistics package such as Minitab. In this way, a questionnaire is an efficient method for collecting data from many respondents. The questionnaire was structured in a way that the respondent did not have to write a great deal and the questionnaire ensured that the data was standardised. The time scale for the research is long enough to allow for delays when collecting data from other schools via post. My employers did also pay for my postage costs, which was helpful. The questionnaire collected factual data for quantitative analysis and students' opinions for qualitative analysis. The production of the questionnaire was simple in terms of being able to be produced by myself and there was 'piloting' of the questionnaire through colleagues who gave advice and constructive criticism. Analysis of the questionnaires was quick, as the statistics package that was used is very user-friendly and produces reliable and appropriate statistical values. Permission was granted by my school for the use of questionnaires with my students and I managed to obtain permission from other institutions for the collection of data.

The questionnaires were worded in such a way that all of the students could understand the instructions necessary to complete the questions and staff at other schools were also given instructions concerning what they could and could not do when they administered the test. The questionnaire was designed so that relatively little time needed to be 'encroached' upon in lessons, therefore causing minimum disturbance to lessons in other institutions. This factor, and possible duplication of questions, was discovered during piloting. The questionnaire was designed to appeal

to a specific audience, either at GCSE or A Level, and the vocabulary was matched accordingly to take account of this. Any questions asked by questionnaire did only enquire about the respondent's own opinions. Questionnaires referred to why *they* and nobody else found a particular area of physics difficult, hence reducing any chance of ambiguity or contradiction. The respondent's opinion was needed, not their opinion of what somebody else would find difficult, meaning that 'hard' factual data was collected about truths rather than mere perceptions. No questions were asked that had a 'don't know' response, neither were any questions given that could be interpreted as being 'leading' questions. Questions that were deemed to be intrusive or politically incorrect were not asked and the original piloting episode did manage to identify, successfully, if these were present.

The questionnaire did only make one assumption which was that the students may have found areas of a syllabus more or less demanding than others, since this was the whole purpose of the research. Questions were made as simple as possible, with the simplest questions occurring first and any longer, open-ended questions asked last of all. The first questions were classed as 'closed', using a fixed Lickert scale, whereas the last questions were classed as 'open' to extract more detail and to avoid the potential inaccuracy caused by a Lickert scale response. This method also helped eradicate any problems involving inter-rater reliability. Unfortunately, highly standardised questionnaires can be frustrating and respondents may find them patronising and over-simplified. It is also difficult to check the truthfulness of responses on questionnaires, especially when external students are questioned who are not known to the researcher.

Interviews: Interviews, like questionnaires, have their relative advantages and disadvantages. The depth of information that can be obtained in an interview is potentially enormous and they can provide great qualitative insights into the research from important interviewees, something that numerical data cannot do to the same extent. Interviews were used in the research because they offered very detailed information based on experiences and perceptions that could not have been identified quantitatively in such an accurate way. Interviewing is also very inexpensive, not requiring the postage costs of questionnaires, if done in one's own institution. The only equipment necessary was a tape and a tape recorder. Interviewing, being less structured than questionnaires, can lead to vital information that would not have been included on a questionnaire and so the interview can diverge, expand and offer greater flexibility which a questionnaire cannot do. Validity of responses can be checked more easily from interviews and interviewees tend to be more 'honest' in an interview environment provided relationships between interviewee and interviewer are good. Obviously, interviews were offered to a number of students, but only those students who offered their consent were expected to provide an interview and those students that did agree to be interviewed were guaranteed complete confidentiality. A small number of interviewees can be justified here, because the quantitative data did provide the correlations whereas the interviews and more qualitative questionnaire questions enhanced the findings by adding more detail to the trends found via the quantitative methods

The questionnaire, being very structured, meant that my interviewing technique was not highly structured. Instead, the interviewing procedure was designed to be semi-

structured because a clear set of questions, obtained through the preliminary research, needed to be asked, but there also needed to be considerable flexibility so that interviewees felt free to express their opinions when they wanted to and how they wanted to. The worst thing would be for the interviewer to have had too much control because this might have increased the bias and lead to 'leading' questions, which would have totally ruined the reliability of the data.

By having semi-structured interviews, ideas and perceptions were allowed to 'happen' of the interviewee's own volition, producing highly reliable, highly significant and honest data.

Each interview only contained 6 questions with no time limit on answers and 30 interviewees were interviewed, 20 from a GCSE background and 10 from an A Level background. The intended approach was passive, neutral and non-judgemental and I tried, as much as possible, to avoid antagonism. This approach was explained explicitly before the interview so as to 'calm' interviewees and the interviewees were questioned afterwards to see whether they were happy with the interview. Each student was thanked for his or her time and given the opportunity to ask questions if they so wished. The transcript was checked with the interviewee to make sure that all facts are correct and the responses of the interviewees were checked via triangulation. Each student interviewed supplied much quantitative data to the research and this was compared with the interview to see if there was sufficient reliability between the various data responses. The consistency and ontological objectivity when interviewing was difficult to achieve since students reacted in different ways to being interviewed, having to speak into a tape recorder or answer questions about

themselves or education. This was difficult to achieve, but I tried to remain aware of my manner when conducting the interview and I conducted the interview in the same room each time, which was a room known to the students and used by them as much as it was by staff. This was done to establish a neutrality in terms of where the position of the work was carried out. All pupils interviewed had either been taught by myself or had been a member of my form class. Relationships with pupils are generally very good and this helped the interviews to be relaxed and comfortable.

Validity and Reliability:

Validity concerns the credibility of results and reliability concerns how consistent the results are. The types of validity and reliability that needed to be addressed will now be discussed along with measures that were implemented to ensure maximum validity and reliability:

Concurrent or Predictive Validity: This means ‘does the data collection technique predict what it is supposed to?’ To try and make sure that this would be true, piloting of questionnaires took place and the preliminary results were used to see whether what the questionnaire was trying to establish had been possible. This does not mean that the results obtained should have been the same as those beliefs held by myself, it means that the questionnaire should have been structured so that it could predict any outcome with accuracy. With a Lickert scale and standardised questions, this was found to be achievable.

Construct Validity: This type of validity is concerned with whether the method of data collection and subsequent quality of measurement is measuring, effectively, what it supposed to be measuring. As an example, if I wanted to determine whether students found radioactivity more difficult than the electromagnetic spectrum then I would design a questionnaire that would ask many students to grade the topics that they have studied from 'very easy' to 'very difficult' along with some response as to why this was the case.

Face Validity: Face validity measures the construct validity. This is based on personal judgement. The question that needs to be asked is 'Does this question or technique measure what it is supposed to measure and will it give better results compared with another technique?'

In terms of reliability, the following aspects needed to be considered:

Test-retest Reliability: When the test is repeated on Friday will it provide similar responses to the results are obtained on Tuesday? The method of data collection should not be highly unstable. Should the results differ with time, it might mean that the data collection method is unreliable. Test conditions such as location should also have no effect. This reliability can easily be verified through statistical methods such as the calculation of p-values. Every step was taken to ensure that this was possible.

Alternate Forms Reliability: The results obtained from one data collection method should correlate highly with the same question, or similar questions, on another form or indeed another type of data collection method, such as interview. This can be

checked via method triangulation and by statistical techniques such as Pearson's correlation.

Inter-Rater reliability: This type of reliability determines whether what I suggest is the pattern or trend in the data agrees with that collected and analysed by someone else. I may judge something as being worth '4 out of 10' and somebody else might judge it as '9 out of 10', showing poor agreement between raters. I did not rely too heavily on this as I did not ask anyone else to 'rate' the research data. The data was collected by a number of people in a number of institutions, but the statistical and qualitative analysis was only performed by myself with as much attention paid to establishing ontological objectivity as seen necessary.

One problem that did occur that students perceived reasonably 'soft' terms such as 'very easy' and 'very difficult' quite differently. One student graded a question as '5' meaning very difficult and one student graded the same question as '4' meaning 'difficult', when in fact they actually perceived the same degree of difficulty. This was virtually impossible and the only way to minimise this was to explain, with examples, when a '4' grade should have been given and when a '5' grade should have been given. In this way, confusion over how 'difficult' was different from 'very difficult' was made more precise, although there was still going to be some subjectivity due to the students' personal interpretations of these definitions.

In terms of internal and external validity, the following are true:

Internal validity: The data collection and analysis showed internal validity because the data collected reflected the trends and patterns of the research within my own institution. The data collected was mostly taken from this sample over a number of years and so any major patterns that arose did so from the data that pertained to these students.

External validity: The research episode focused only marginally on data collected from other institutions; most data came from my own institution. However, my school is an independent school, so it was felt to be inappropriate to try and claim any external validity with respect to the state sector, since cultural bias would be present. It would only be possible to claim external validity when enough high quality data was received from state schools and only if enough data from a number of different questions or interviews was obtained. Obviously, for the research findings to be deemed significant then data from other institutions needed to be collected so that claims about the treatments can be claimed to be true. Other independent and state schools have provided some preliminary data on difficult concepts and working memory, but not a sufficient percentage of the data for it to allow a significant claim for external validity.

Issues concerning Ethics and Confidentiality:

When collecting the research data, certain measures needed to be implemented so that nobody involved was made to feel uncomfortable. All of those people interviewed have been assured that their names would not be used in the thesis or any subsequent

work. Those people involved in the contribution of data may be quoted verbatim, but they will be referred to by a code and themselves and myself will only know their true identity. All of those people involved were told that under no circumstances would their name be used, regardless of whether they agree to this or not. This decision was taken to ensure that there could be no possibility of controversy or breach of trust. This method also makes the confidentiality issue standardised and 'tight'. If some people were given 'immunity' and others not then the whole issue of confidentiality would have become extremely untidy. The only option, it was decided, was to implement complete confidentiality.

On an ethical level, there was a problem with which groups received the treatment and which groups did not. I had decided to use some of my groups as control groups and some of them as treatment groups, that is, the treatment group would receive the thinking skills materials and strategies and the control group would receive nothing. The problem concerns fairness and professional responsibility. Why were some groups being disadvantaged? My answer to this is that all groups would eventually receive the thinking skills strategies in all lessons if it is found that they improved understanding. There was no real alternative to this and it is the same problem when compared to other areas such as trials of new drugs in medicine, where some people receive a new drug and others have to go without until it is found whether the drug is indeed effective. Since thinking skills strategies are transferable and not subject specific, then the ethical issue was not too disadvantageous. Other members of staff in my department who do not have an interest in the thinking skills procedure would

also be providing me with data as a control group where no thinking skills strategies were in use. There are no real ethical issues here since personal belief and choosing to further one's own professional development are personal issues that cannot be addressed.

Unfortunately, if the thinking skills strategies were found to augment learning then it is not just a simple case of giving other professionals a teaching pack and asking them to 'get on with it'. Much training and background reading would be necessary so that teachers can become au fait with the area of thinking skills tuition. This was also an ethical issue because allowing staff to teach thinking skills strategies without the appropriate in-service would have caused more harm than good.

Chapter Three

Preliminary Investigation – Students’ Perceptions of Difficult Concepts in Physics

The first part of the research was to try and discover whether the following hypothesis was correct: Do students tend to agree that certain aspects of physics are more difficult than others? To discover whether this hypothesis was true, a preliminary sample of 54 Year 11 GCSE students from two schools was given a questionnaire concerning its views on the relative difficulty of topics that they would have studied as part of their GCSE separate science Physics course. The questionnaire was composed of 36 topics that students were asked to consider and then grade, in terms of difficulty, from 1 to 6, based on a Lickert style scale. A response of ‘1’ by the student indicated that they felt that the topic was ‘really easy’ and posed no problems, whereas a response of ‘6’ indicated that the students found the topic or area of the syllabus ‘very difficult’ to understand. A copy of this questionnaire is included at the end of this thesis.

The preliminary results were then used to produce a rank order of difficulty of the 36 areas based on the responses given by the pupils. The scores for each of the individual areas were then used to find a mean value of difficulty for each of the areas. The rank order was then produced. The most difficult areas of the syllabus would have the greatest mean values (closest to 6) whereas the parts of the syllabus that the pupils found easiest would have the lowest mean values (closest to one). Having determined which areas the

pupils found the most difficult and the least difficult, the preliminary analysis then focused in on the five most and least difficult areas, to make subsequent analysis less difficult and more manageable.

The five most difficult areas of the physics syllabus as indicated by the pupils are listed below along with the mean value of difficulty:

Table 3.1 The five areas of the GCSE physics syllabus deemed to be most difficult.

1. Nuclear Fission	(3.95)
2. Transistors	(3.85)
3. Radioactivity	(3.50)
4. Life Cycle of Stars	(3.30)
5. Diffraction	(3.25)

The five areas of the GCSE Physics syllabus that the pupils found least difficult, along with their means, are listed below:

Table 3.2 The five areas of the syllabus deemed to be least difficult.

1. The 13A Plug	(1.55)
2. Renewable Energy Resources	(1.79)
3. The Solar System	(1.80)
4. Day, Night, Year, Seasons	(1.95)
5. Simple Circuits	(1.95)

As well as the pupils' opinions, a number of physics teachers and good AS/A2 level students were asked to give their opinions to see whether this preliminary data did have some agreement with their more erudite 'expert' opinion.

The correlation between the mean value obtained from pupils and the mean value obtained from teachers and other experts was 0.837, with a p-value less than 0.001. This shows a very high correlation and a very high statistical significance. The pupils' opinions agree with the experts' opinions in such a way that it would be highly unlikely for this agreement to occur on the basis of pure chance. The 'experts' included other physics teachers, physicists, lecturers and high achieving A level and degree level students.

Although useful, correlation coefficients and p-values do not necessarily *prove* anything. In other words 'correlation is not causation'. Despite the initial result that pupils and teachers agree on the level of difficulty, it is imperative that the investigation tries to determine why this is actually true.

To help identify each individual student's problem with an area of the syllabus that they found difficult they were also asked to decide which area they found 'especially difficult' and also one area that they found 'especially easy' and then to comment on why they had chosen these particular areas. The results obtained from this preliminary research, along with some anecdotal comments made by individual students are shown below. For reasons concerning confidentiality, a unique student number that was used when analysing their data statistically using a statistics package has replaced the pupils' names.

The most notable trends obtained from the preliminary research questionnaire.

1. Most students found transistor circuits really difficult to understand because they could not 'see' how the symbol for the transistor made the circuit work, unlike 'simple series circuits where you could follow the current round in your head'. One A level student (student #23) commented:

"...The concept of the transistor being made up of the three layers (base, emitter and collector) and the voltage having to be above a certain value before the transistor conducts fully is hard to comprehend. It is also hard to understand what happens in transistor circuits when components in the potential divider arrangement are swapped around. What makes this hard to grasp is the fact that when the resistance goes up across a component, it means current can flow in the collector-emitter circuit. You would get confused here because as the resistance goes up, the current, you would think, should go down. It is not possible to understand the transistor's workings unless the whole circuit is looked at."

2. Certain students did not like mathematical topics. They found the maths equations hard to remember, manipulate or use. Lower ability students in the groups tended to find any maths daunting and their responses on the questionnaire were: " I don't like maths." One GCSE student (student #10) said: " *I did not like centripetal force work because I did not*

understand the maths." The more able GCSE students generally liked the maths content and one student (student #17) stated: "*I did not like the solar system work because it did not have any calculations in it.*" The most able students did comment on the difficulty of the maths, but on a more sophisticated level. One student (student #5) asked: "*why is the centripetal force equation not just $F = mv/r$?*"

3. The nature of 'invisibility' in certain areas of the work was a major problem for virtually every pupil, regardless of ability. Students commented on the fact that the difficult material could not be 'seen' and was not tangible. Many students found it difficult to see or accept the physics surrounding nuclear fission and one pupil (student#11) stated: "*there were too many new concepts involved and I could not see how and why the radiation was given off.*" Many students agreed on the nuclear fission topic as being the most difficult, but they found it frustratingly difficult to explain exactly what is was about the topic that caused such problems. The general consensus was that it was new, invisible and very strange, unlike the planets or the 13A plug, which was very easy.
4. Those topics that were towards the formal operational thinking side of the Piagetian framework were generally agreed to be the most difficult by students and teachers alike. These topics are deemed to be more difficult because they place greater demand on the student's thinking. The demand of formal operational thinking is not present in concrete operational thinking. Concrete operational thought does not place students in the position where they have to consider more than one independent and dependent variable simultaneously. Some students found Boyle's law, the transformer equation and

multiplicative compensation problems difficult because of the multivariate nature of the area.

5. Areas of the syllabus which involved the learning of many pieces of information caused problems for a large number of students across the ability range. The most notable of these was the Life Cycle of the Star. Many students, across the ability spectrum, found this part really difficult because there was so much information to learn that was new, difficult to accept and because of its sheer volume. One student (student #3) remarked: “ *it was hard to accept and we went through so much so quickly. I would like to do it again in smaller bits.* ”
6. Vocabulary, although not a major problem, did cause a few concerns for a small number of pupils. Some pupils confused transistors with transformers and others confused moments with momentum. A number of pupils, when learning about stars and the evolution of the universe, found it hard to remember and re-use or apply the following terms in the correct order or sequence necessary for answering a structured GCSE question: protostar, red shift and blue shift, red giant, white dwarf, main sequence, supernova, radiation pressure and gravitational force. One student (student #33) commented: “ *it was like a languages lesson! Loads of big words and they just didn't mean anything to me! The other thing was you had to learn it all in the right order and it got more and more confusing.... My head was spinning at the end of that lesson!* ”

7. When pupils found an area difficult, it was often because they did not find it interesting either. One student who liked electronics stated: “ *I did not like the Earth and Space stuff because it did not interest me. When I do revision I always avoid it because it's boring.* ” Another student (student #20) wrote: “ *I could not understand or remember the circuits stuff and that made me mixed up and I didn't want to do it because I did not enjoy it.* ”
8. The areas of the syllabus that students found most straight forward were those that had little mathematical content, were simple in terms of the amount of information that had to be learned, were known to them from previous stages in their education, had simple vocabulary and were visible. The most popular easy area was the plug because it could be seen around the house and students had commented that they had been shown how to wire a plug by their parents when they were younger. The pupils also knew that they only had to remember a few facts about the plug such as the colours and positions of the wires, the purpose of the fuse and other simple safety features. Another easy area was the solar system. Pupils commented on having learned about this before, reading about it as a child, knowing about it because the content is visible and knowing about the planets from books and television. Some students agreed that the easier content was easier because they felt as though they existed ‘inside it’ rather than ‘outside’ it.

Chapter Four

Difficult Concepts in Physics-a Review of the Literature.

In this chapter the evidence for why certain areas of Physics are more difficult than other areas will be addressed. There are a number of different theories for why certain topics or areas are seen as being more difficult than others and these have been well documented by experts in the field. The preliminary research carried out by myself has also shown agreement with some of the areas that will be addressed now.

The main areas where 'difficulty' resides concerning the learning of Physics in secondary education are listed below:

1. The nature of memory, working memory and 'chunking' (Miller, Baddeley, et al.).
2. The nature of science: macrophenomena, sub-micro level phenomena and symbolic knowledge (Johnstone et al.).
3. Concrete and formal operational thought (Piaget).
4. Multiple intelligences and multiple solutions (Gardner, Kibble, Tao).
5. Mathematics (Butterworth, Raw).
6. Language-based phenomena (Sutton).
7. Confidence and metacognitive self-regulation.

Evidently, no list is exhaustive, so there may be other areas where difficulties arise, but from preliminary research and work carried out by researchers in the field, these areas would appear to be the ones where much of the problem lies.

1. The Nature of Memory, Working Memory and 'Chunking'

A major area of research in this field concerns memory and how the internal structure of memory affects learning. Miller (1956) suggested that mental processing was dependent on how many pieces of disparate information the brain could handle at once. He claimed that the brain could store 7 ± 2 pieces of information at any one time. People can store up to seven pieces of information relatively easily, but at 7 items there is a very critical change in memory performance as the working memory starts to become 'overloaded' with information to remember. Considerably above 7 items, people just cannot store the volume of information. However, as Miller (1956) freely admits, there is nothing particularly 'magical' about the number 7 and more recent work (Halford, 1993, Cowan, 2001) would seem to indicate that the working memory has a more precise capacity limit of no more than 4 chunks of information.

A Brief History of Short-Term Memory and Working Memory

The distinction between a limited-capacity *primary memory* and an unlimited-capacity *secondary memory* was, arguably, first proposed by James (1890). The notion of primary and secondary memory became central to Atkinson and Shiffrin's (1968, 1971) *multi-store model* where the primary and secondary memory components became *short-term memory* and *long-term memory*, respectively. The multi-store model was seen as being very successful since it 'explained' the nature of this type of memory as being:

- a) of limited capacity;
- b) of limited duration (15-30 seconds unaided, but increased with rehearsal).
- c) of mainly acoustic, semantic and (possibly) visual in its coding.

Atkinson and Shiffrin's multi-store model was often called the *dual memory model* since there was an emphasis on short-term and long-term memory and a brief description of this model is provided in the appendices.

The multi-store model saw the short-term memory as a system for temporarily holding and manipulating information (Gross, 2001). However, Baddeley and Hitch (1974) believed that despite the short-term memory's obvious ability to process and rehearse information for storage in the long-term memory, there was more to the short-term memory than it being merely a 'stopping-off station' for information (Gross, 2001). According to Groome et al. (1999), *short-term memory* is an active store used to hold information that is being manipulated, *working memory* is a mental workspace where various operations are performed on current

data and *long-term memory* is where large amounts of information are held in a fairly passive state for retrieval at a later time. Working memory is a cognitive function that, in simple terms:

- a) helps us keep track of what we're doing or 'where we are' from moment to moment.
- b) Holds information long enough to allow us to make a decision, dial a telephone number or repeat a strange, foreign word that we've just heard (Gross, 2001).

The term 'working memory' is often misunderstood and is used by different people in different ways. The definition used here is: "*working memory is the use of temporary storage mechanisms in the performance of more complex tasks*" (Hulme and Mackenzie, 1992) and Haberlandt (1997) also explains working memory, very simply, as '*where the action is*'. When, for example, a piece of text is being read from a book, the information that is entering the brain has to be temporarily stored in memory. If this did not happen the text would merely appear as individual words which could be read, instantly forgotten and then obviously not connected to any other incoming information to make 'sense'.

As Hulme and Mackenzie (1992) state: "*working memory.....is necessary in order to compute the semantic and syntactic relationships among successive words, phrases and sentences and so construct a coherent and meaningful representation of the meaning of the text. ...Working memory is the system or set*

of systems responsible for the temporary storage of information during the performance of cognitive tasks”.

Baddeley and Hitch (1974) designed a model for the working memory which would explain how the brain collects information from text and then retains it for integration with other text over a short period of time. Baddeley (1986) describes working memory thus: “ *a limited capacity central executive interacting with a set of passive slave sub-systems*”.

The two slave sub-systems that Baddeley described were the ‘*speech-based articulatory loop*’ and the ‘*visual image scratch-pad*’. The first of the aforementioned is concerned with performance of the memory span and the second is concerned with the short-term memory of visuo-spatial information.

The ‘*central executive*’ is responsible for the movement and integration of information and it only has a small capacity for information storage. The central executive could be seen as a very complex construct, responsible for the selection and execution of particular strategies. However, despite the model making it complex, it is also quite vague since it is not fully understood. The main problem with the role of the central executive is that it has (limited) *storage* capabilities as well as possessing *processing* capabilities. Some information can also be contained in the articulatory loop.

The articulatory loop is very important because information can be stored here without affecting the processing capacity of the central executive that can then keep receiving, retrieving and integrating information for understanding.

A useful description of the articulatory loop is given below (Hulme and Mackenzie, 1992): “ *A useful analogy (of the articulatory loop) is tape loop of specific length which can hold a message that fits onto the length of tape. The temporal duration of the message will determine whether it fits onto the tape loop. If it is too long the message will not fit on the loop and will be lost or will have to be stored in the central executive.* ”

A loop of tape could, then, store one piece of information of length 20 minutes or two pieces of information of length 10 minutes or five pieces of information of length 4 minutes, etc. By this analogy, the number of pieces of information, such as single words, that can be fitted on the articulatory loop depends on the time it takes to articulate the information.

Baddeley determined a direct correlation between the reading rate and the memory span, which can be explained mathematically as:

$$\text{Words held on loop} = \text{length of loop} \times \text{speech rate}$$

So, a person may be able to read 8 words per second and have a loop length of 1.5 seconds. This means that they would have 12 words stored on the loop for subsequent use by the central executive. For longer words, which take longer to say, the speech rate might only be 4 words per second which would give a value of 6 words held on the loop in that time. The summarisation of this work was that Baddeley et al. showed that subjects could recall as many words as they could read in 1.8 seconds and work carried out by Standing, Bond, Smith and Isely

(1980) confirmed that this value was between 1.8 and 2.2 seconds. Standing, et al. noticed from research data that bilingual subjects produced lower values for loop length and speech rate when tested on their second language (1980).

Further work done on the notion of the articulatory loop by Schweickert and Boruff (1986), Naveh-Benjamin and Ayres (1986) and Ellis and Hennelly (1980) suggest that the articulatory loop had a value for the number of words that could be remembered in 1.83 to 2.13 seconds. This value range not only applied to English, but also to research done in English, Spanish, Hebrew and Arabic.

One way of trying to understand how the working memory works involves the performance of a task such as trying to remember the number of windows in your house (Baddeley, 1995). The majority of people try to do this by visualising the image then by taking a 'mental journey' through each of the rooms in turn. To set up and manipulate the image we need the visuo-spatial scratch pad and to sub-vocally count the number of windows we use the articulatory loop. The whole operation is organised and run by the central executive.

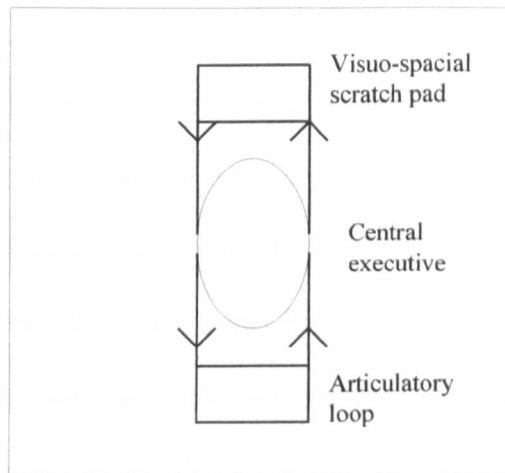
Recent work performed at the University of Glasgow by Alex Johnstone has added much credibility to the argument that the limitations of an individual student's working memory have a significant effect on their ability to answer examination questions of different 'Z demand' or difficulty. Johnstone noted from the data that he had collected on 20,000 students that there was a sharp decrease in the fraction of the students correctly answering a chemistry problem when the Z demand reached a value of 6. When comparing the students' performances with

their performance on working memory tests, Johnstone noticed a pattern. The pattern was that the better the working memory of the student, the more likely they were to successfully complete questions of high demand. The surprising finding about the data was the sharp drop in the percentage of correct responses from 90% to 20% at the $Z=5$ to $Z=6$ transition of task demand (Johnstone, El-Banna, 1986). Another interesting finding in the same study was that students with working memory capacities of $X=5$ and $X=6$ could not successfully complete questions of demand $Z=7$. When students were given a chemistry examination at the university it was found that none of the questions were given a Z demand of 6, so students with capacities of $X=5$ and $X=6$ obtained similar results.

Working memory research carried out at the University of Glasgow in the solving of physics problems (Johnstone, Hogg, Ziane, 1993) has also shown that there is an important link between how questions are interpreted and understood and the working memory of the individual. The results obtained in this work also show that the simplified structure of the same question by adopting a chunking approach, an aid to temporary visual storage and a 'noise' reduction technique can lead to greater success in examinations. As stated in the paper " *If we are to use questions to assess competence in physics, the form of the question is important...or we may just be testing not so much the physics but a psychological artefact such as working memory space.* "

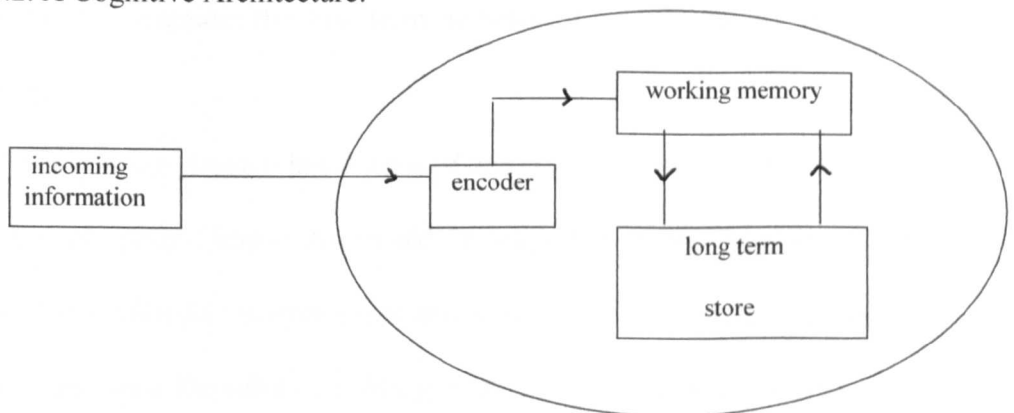
A model of Working memory designed by Baddeley and Hitch is shown over the page. The three areas of the model are the visuo-executive and the articulatory loop; it is the loop that is of most interest.

Figure 4.1 Baddeley's simple representation of the working memory.



The figure below shows how the working memory interacts with and plays a part in general 'cognitive architecture' (Newton, 2000).

Figure 4.2. A Cognitive Architecture.



In figure 4.2, *incoming information* is information that occurs via the sensory memory, *encoding* is the transformation of sensory input into a form which can be registered in memory, *working memory* is the temporary store where information is held long enough for a decision to be made and *long term memory* is the large, passive store of episodic, semantic, procedural and declarative memory. Further details are provided in the appendices.

If the research concerning working memory and chunking is to be deemed credible and appropriate, which I believe it is, then it would be useful for the development of a thinking skills-based Physics teaching and learning module in schools. The idea that there is an ‘upper limit’ to memory span time, determined by the articulatory loop, and that information can only be processed and remembered up to a certain level based on 7 ± 2 (or 4 ± 1) ‘chunks’ of numbers, letters, words etc. will have major implications when trying to optimise learning capacity. Such strategies for optimising / maximising the amount of information that can be processed and handled at any one time could include mnemonic representation, or a rhythmic approach coupled with reinforcement to help working memory augment the long-term memory of relevant pieces of Physics information.

Whilst discussing the possible importance of working memory, it is also necessary to consider alternative ideas. As would be expected, some members of the academic community do not even agree that it is necessary for temporary storage concepts at all, since the rules of learning could be identical in the short and the

long term (Cowan, 2001, Neath, 1998). Other academics suggest that there may not be an actual limit in storage capacity per se, but a limit for the time in which an item can remain in short-term memory without rehearsal (Baddeley, 1986) and others have suggested that capacity limits exist but that they are completely task-specific and so a general estimate is not really feasible (Cowan, 2001). Whilst it is important to realise these beliefs, they have only been exposed here to show the alternative views, but they will not form any part of the research programme.

2. The nature of science: macrophenomena, micro level phenomena and symbolic knowledge.

The nature of the science itself must have an enormous effect on whether a particular student finds a piece of work easy or difficult. Recent research carried out by Johnstone (1991), discusses the structure and nature of science and looks at three areas, namely macro, sub-micro and symbolic material and uses these categories to explain why it is 'difficult'.

a) Macrophenomena:

Macrophenomena concerns the visible and the large everyday aspects of Physics that we see, feel, touch and recognise with ease. Macrophenomena could include moving cars, oscillating springs, shooting stars, loud explosions, refracting light rays and spiky hair produced by the Van de Graaff generator. These all have some

tangible nature that makes them believable and it is not too difficult to accept the macrophenomena that are taking place. As the author says:

“ Was there ever a time when school science was easy to teach? The answer must be a qualified ‘yes’. There was a time when physics was concerned with nothing smaller than a brick...Everything came in well designed, closed boxes and the exams explored the contents of each box and never asked pupils to look in two boxes at once.” (Johnstone, 1991).

Students will accept that placing an ammeter in series with an electrical component, in a complete circuit, allows the current to be measured. Students will also realise that changes can be made to the circuit so that the current displayed on the ammeter will change. Changes made to the circuit could include changing the length, cross-sectional area or temperature of a resistance wire placed in series with, say, a filament lamp. Students can actually see how the changing of an independent variable affects the current. What they do not see is the actual electrons that are flowing in the circuit and the changing vibrations of the fixed metal atoms that the electrons are trying to get past when the temperature of the wire changes. This problem occurs on a very regular basis when the visible, tangible nature of Physics suddenly becomes the invisible and the intangible. This is when **macrophenomena** become **sub-micro** phenomena. Sub-micro phenomena in physics at school level can also include photons, nuclear and sub-atomic particles, radiation and neutrinos as well as other invisible or intangible ‘objects’.

b) Sub-micro phenomena:

Sub-micro phenomena are the pieces of physics that deal with the invisible and the intangible. The problem occurs here because pupils cannot see these things, but can see the effect that they have. For example, pupils will be convinced, quite easily, that a piece of radioactive material is giving out radiation of some sort. The teacher might then expose the three most common types of radioactive emission, namely α , β or γ . Students will also be happy when asked to decide which of two radioactive materials is most radioactive, simply by comparing their activity with the use of a Geiger counter. However, trying to get students to *visualise* exactly what is happening is very difficult and so the area of, for example, 'quantum mechanical tunnelling' or the continuous energy spectrum for β decay will be very difficult to visualise. To make matters worse, physics is further complicated by the third area of *multilevel thought* (Johnstone, 1991) known as symbolic knowledge.

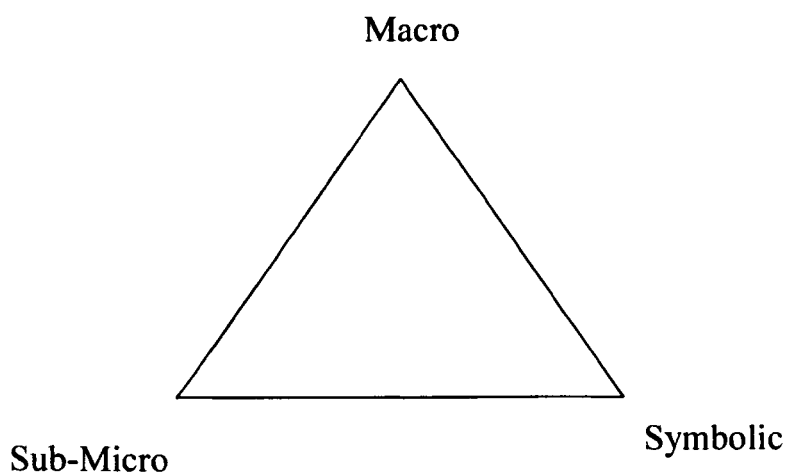
c) Symbolic Knowledge:

Symbolic knowledge concerns the mathematics and formulae of physics: the representation of the tangible macrophenomena in symbolic form. Using the example of a circuit again, the student will move from the macroscopic circuit itself to the symbolic representation of its behaviour via the use of equations which refer to charge, current, potential difference, energy and power. Not only do

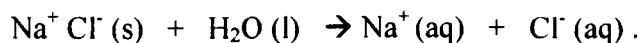
these equations need to be learned, but manipulated and understood in relation to one another.

Johnstone describes these three levels of macro, sub-micro and symbolic knowledge as three points on a triangle. This is shown below:

Figure 4.3. Johnstone's model of multilevel thought.



Johnstone argues that it is not necessary to overburden students with too much information that belongs to all of the three levels simultaneously. A lesson in chemistry may start with the teacher showing a class of pupils some substances and then continue by dissolving them in water. The pupils can see this and so the easier macro level material has been understood. Within a matter of seconds, the teacher may have explained this on the board as:



This symbolic nature of the explanation may have worked with some of the class, but there may be a large number of people still ‘stranded’ at the macro level corner. Johnstone (1991) argues:

“ There has been a suggestion that worthwhile science can be done only when juggling at all three levels, but this is patent nonsense. ...Some of the most taxing science is done on two levels only, for example, classical thermodynamics uses only the macro and the symbolic levels.”

Expanding on Johnstone’s ideas, I have constructed a table showing the possible multi-level structure of certain areas in the current secondary school, GCSE, Physics syllabus:

Table 4.1. Examples of multilevel topics in GCSE Physics.

Topic / Area	Macro level	Sub-micro level	Symbolic level
The Solar System	YES	NO	NO
The 13A Plug	YES	NO	NO
Energy Resources	YES	NO	NO
Momentum	YES	YES/NO	YES
Life Cycle of Stars	YES	YES	Not at GCSE level
Nuclear Fission	YES	YES	YES
Transistor Circuits	YES	YES	YES

table above is intended to serve as a comparison between different areas of the GCSE Physics syllabus taught in schools. The topics that the students found

easiest when questioned for the preliminary data appear to be at the macro-phenomena level of the curriculum. The topics of the solar system, the 13A plug and energy resources place the lowest demand on students' thinking. Concepts are learned and accepted based on experience, often everyday experience in the world around them. These three aforementioned macro areas are tangible and 'closed'. The content is learned and 'regurgitated' at the exam end of the course.

Taking the 13A plug as the main example, the student is expected to know only a few facts which are:

- the names of the parts of the plug
- the colours of the wires
- the names of the wires
- where the wires go
- safety aspects of wire connection.

The learning of this part of the syllabus takes a short time and pupils will possibly be asked to totally disassemble and then re-build a standard plug. There is virtually no sub-micro content to deal with and there is no maths at this stage involving, for example, calculations to prove the best fuse rating to use in a plug for a particular appliance. Questions about the plug are often confined to exam papers that test grades C to G, since it is not demanding enough to place in the A* to B bracket.

After these 'easy' topics that rely solely on the macro-phenomena level, there are the topics that have a macro level part as well as a symbolic part. For example, the topic of momentum has a macrophenomenological part as well as a symbolic level part. Students are familiar with collisions, crashes and bangs, air-tracks etc., and they tend to really enjoy them. This behaviour is very much tangible, audible and visual so is definitely macro-phenomena. A common demonstration involving the law of conservation of momentum involves dropping a basketball and a tennis ball, which are in contact, onto the floor. The balls, in contact, fall downwards at the same speed towards the ground. Upon collision with the floor, the basketball bounces up at a small speed and the tennis ball, due to its smaller mass, bounces up at a much greater speed, in accordance with the law of conservation of momentum. On a verbal level, students tend to accept this because they have seen it and it tends to make 'sense'. The tennis ball has less mass, so the same 'bounce' up will move it further than the bigger basketball.

Unfortunately, the introduction of mathematics then 'loses' a large proportion of the students. To make matters worse, momentum is complicated by other factors such as the 'vectorial' nature of velocity, the elastic or inelastic nature of the collision and the angle of recoil and the fact that kinetic energy need not be conserved during a collision. Evidently, what was previously a simple macro-phenomena level problem is now much more multivariate.

Consider the following diagram which shows the problem as it may be represented graphically for the students:

Figure 4.4 (a) 'before'

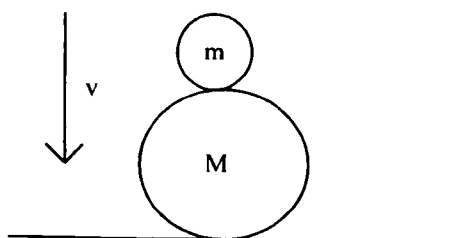
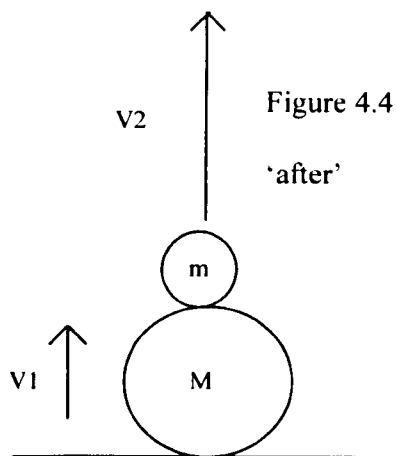


Figure 4.4 (b)



The problem occurs when the symbolic knowledge begins. To explain the system 'properly' involves the following two equations which explain the requisite physics, namely the conservation of energy and linear momentum:

$$Mv - mv = mv_2 + Mv_1$$

$$\frac{1}{2} Mv^2 + \frac{1}{2} mv^2 = \frac{1}{2} mv_2^2 + \frac{1}{2} Mv_1^2$$

Understandably, the demand on learning becomes greater despite the fact that the pupils have managed to come to terms with the basic physics. To make the

problem of how symbolic knowledge affects learning even more apparent, the physics involved when three balls are dropped that are in contact does not change, but the symbolic knowledge required to solve the problem becomes horrendous. The general solution (Anderson, 1999) to the problem of the speeds of the balls, after much mathematical rigour, is:

$$V_n = (2^n - 1) v_0$$

where V_n is the velocity of the uppermost ball in a system containing 'n' balls and V_0 is the common downwards velocity of the 'n' balls before they bounced. By conservation of energy, $V_0 = (2gh)^{1/2}$, where 'h' is the height from which the balls have been dropped and it is assumed that 'h' is very much greater than the radii of the balls.

Despite the fact that most students, and many teachers, would not be able to arrive at this result, the vast majority would correctly predict that the lighter the ball, the faster its recall velocity. This problem may cause some to ask whether it is not a better idea to adopt an 'optimisation' of understanding technique that applies to the majority of the population rather than trying to cater for the few gifted students whilst the rest sit in almost complete ignorance.

A common investigation at GCSE level is one involving pupils to investigate how high different balls will bounce after landing on a particular surface. Virtually

every student will be able to predict the order based on their everyday experience, a fact that is closely related to the macrophenomena level of the investigation. The problem occurs when the students have to explain why they think, say, a golf ball will bounce up higher than a squash ball. The problem here is that the new knowledge required to explain the behaviour of the balls is both symbolic and sub-micro. Since pressure, volume, elasticity and temperature affect the results, there will be problems concerning which equations to use and also how the structure of the material may affect the bounce. Problems may also occur because of the difficult concepts such as forces, pressure and energy having to be considered when formulating the mathematics in the problem.

The most difficult areas identified by students in their learning of physics material at GCSE were nuclear fission and transistor circuits. In terms of Johnstone's model, nuclear fission has all the attributes of being a difficult area to learn effectively. First of all, despite it having obvious macroscopic properties, such as nuclear power stations and the production of electricity, the macroscopic nature of this is still fairly invisible, since you only see the effect of the fission not the fission itself. Also, nuclear fission requires symbolic knowledge such as the use of nuclear equations to represent types of radioactive decay and it is sub-micro because the fission process itself cannot be seen and requires some quite strange ideas. What the pupils find especially hard is the fact that the conservation of energy, which was always taken as being an unbreakable law, is strangely interwoven with this new idea of binding energy that contradicts previous

knowledge and is extremely difficult to visualise in simple, everyday understanding.

Transistor circuits are difficult to comprehend for similar reasons in that the sub-micro and symbolic levels of multilevel thought are very prominent and that the macro-level is slightly hidden. From the moment pupils start learning about transistors they experience problems.

The most common problems that have been identified via the preliminary data are:

- The transistor symbol itself is confusing
- The three parts: base, emitter and collector are poorly understood in terms of necessity, function or operation.
- Why a small base current makes a bigger collector-emitter current.
- The transistor can be a switch or an amplifier.
- The potential divider equation and underlying logic, involving Ohm's law, are hard to accept.
- Unlike a bulb, the internal workings of the transistor cannot be 'seen'.

Johnstone believes that in order to 'see' Physics at its best, the student needs to be taught in such a way that the three corners of the triangle should be seen at once and that students should not be expected to move, almost effortlessly, from the macro corner to the sub-micro corner. Much work still has to be done concerning

the best way to deliver the more difficult material without overwhelming the child completely.

It is necessary to mention that Johnstone's model is actually based on the behaviour of chemical systems, since Johnstone is a chemist not a physicist. There are, therefore, limitations of this model when applied to physics, but the ideas are similar. In my opinion, Johnstone's model is somewhat limited because it is based on the *content* of the work that students study and it fails to include any psychological reasons as to why certain material is found to be difficult. However, despite this problem, I still find Johnstone's ideas to be very pertinent.

Students' ideas concerning the nature of science

Research conducted about students' understandings of the nature of science (Driver et al., 1996) is also of interest. Driver argues:

" There is an important argument that school science, if it is to contribute effectively to improved public understanding of science, must develop students' understanding of the scientific enterprise itself of the aims and purposes of scientific work and of the nature of the knowledge it produces".

Driver continues to explain that there are two areas of concern in the understanding of science. One area concerns the science content itself and this relates directly to the behaviour of the natural world. The second area relates to

the student's knowledge of science itself, the nature and status of science as opposed to the natural laws that describe nature. Scientific knowledge is the 'language' that describes nature and 'knowledge about science' is the meta-language that describes scientific knowledge.

One of the problems that might occur is the acquisition of scientific knowledge may rest in a poor understanding of the meta-language. Students may not see 'the point' behind a learning episode and so the actual non-importance of the work to them may cause it to become more difficult than it should be. Despite this argument not having the same psychological 'prowess' as other areas mentioned, such as working memory overload, it is still, in my view, very important from a sociological perspective. Students learning from textbooks or via practical work may not really engage themselves fully in the scientific process. If the students were learning about radioactivity, it may not be immediately apparent to the students exactly why they were investigating the behaviour of gamma rays. If the students were introduced to the lesson by some event of sociological importance such as the *'irradiation of strawberries by Sainsbury's on the high street to preserve them, make them last longer and make them less likely to cause us any tummy upsets'* then students might find that the accessibility to the science has increased and so find the science less daunting. In my view, based on the work carried out by Driver, Millar, Leach and Scott (1996), an emphasis on the importance of science in society in conjunction with the scientific processes necessary may help move knowledge from the sub-micro to the macro level. Thomas and Durant (1987) have argued that there is a need for public

understanding of science for number of reasons. These issues are: economic, utilitarian, democratic, cultural and moral. My argument is that students could gain greater access to science through these more tangible, everyday ideas. Driver (1996) states that knowledge of the nature of science supports successful learning in science and that confusion may occur when students are expected to provide conclusions in the classroom based on the limited data that they have collected. Maybe it would be a good idea to make the classroom 'bigger' by involving more of the outside world and therefore increase its credibility.

3. Concrete Operational and Formal Operational Thought:

The role of Piaget's ideas in educational psychology are fundamental to teaching. Most of the theory underpinning 'thinking skills' materials in education is dependent on Piaget's thinking and research. For this reason, the major discussion of Piaget's work concerning Concrete and Formal Operational thought will be dealt with in chapter 4. Here is brief summary of what is meant by concrete and formal operational thought and how it might cause certain areas in the physics curriculum to be deemed 'difficult'.

In simple terms, a concrete thinker will only be able to deal with problems that involve very few variables. The concrete thinker can carry out simple problems

and *describe* what is happening based on their own ideas, but cannot *explain* what is happening (Shayer, Adey, Yates, 1988) in terms of a broader scientific context or scientific understanding.

Formal operational thinking involves a more sophisticated type of reasoning and logic. Formal operational thought requires the student to be able to consider the effect of two or more variables on a problem and be able to control the variables so that it can be decided exactly what the relative effect will be of one particular variable on a problem compared with another. A formal operational thinker would be able to control variables and exclude those that were irrelevant; they would be able to consider and explain behaviour in terms of ratio and proportionality, compensation and equilibrium and probability and correlation (Shayer, et al., 1988).

As a simple comparison between the two types of thinking, imagine that a class was set a problem which was to investigate the factors that affected the time period of a simple pendulum. The concrete thinker would be able to state : "As the pendulum gets longer, the time period gets longer". This would be the concrete thinker's upper limit to the task's demands. Conversely, the formal thinker would be able to state the same, but, would also consider the affect of pendulum bob mass and the angle of release of the bob in formulating a final conclusion. The formal operational thinker would be able to say, after some quite considerable research, that: "as the pendulum doubles in length, the time period increases by a factor of root 2". The concrete thinker might 'guess' that: "as the length doubles,

the time period doubles, also”, which is a ‘sensible’ guess, but wrong and based purely on personal belief rather than scientific rigour.

The real importance behind Piaget’s work here is that it can be used to quantify the current learning stage for individual students. Children can be assessed to determine exactly where they are on the ‘spectrum’ from pre-operational thought to late formal operational thought. From here, strategies can be implemented to try and ‘accelerate’ students from the more concrete to the more formal ways of thinking (Shayer, Adey, Yates, 1988). This is obviously of much importance in the design and execution of lessons and will be expanded upon in subsequent chapters using the ideas of metacognition, cognitive conflict, bridging and transfer. However, despite its importance in teaching, researchers and practitioners do freely admit that it is probably not possible to get all learners to a state of formal operational thinking; there must be something else, neural or genetic, present in the first instance so that the child can develop cognitively.

4. Multiple Intelligences and Multiple Solutions .

Howard Gardner’s theory of multiple intelligences (1983, 1991) has caused great interest in education circles across the world. The basic theory is that there are eight types of intelligence, namely: *linguistic, logical, musical, spatial, bodily kinaesthetic, interpersonal, intrapersonal and naturalistic*.

Gardner argues that these intelligences are relatively independent of each other and children will be predisposed to one type of intelligence.

As Gardner (1983) states in his book 'Frames of Mind' the following criteria lead him to distinguish his areas of intelligence:

- 1) The potential isolation of the area by brain damage.
- 2) The existence of idiot savants and other 'exceptional' individuals
- 3) An identifiable core operation/set of operations
- 4) A distinctive developmental history, along with a definable set of expert 'end-state' performances
- 5) Evolutionary history and plausibility
- 6) Support from experimental psychological tasks
- 7) Support from psychometric findings
- 8) Susceptibility to encoding in a symbol system.

There is certainly some evidence to suggest that Gardner's theory is well founded. Gardner's work is based on neo-Piagetian ideas, especially the developmentalistic nature of intelligence that Piaget developed. The developmentalistic approach adopted here is both academic and environmental in nature. Gardner's theory appreciates the role of the genes in giving us our individual talents, but it also accepts that time and the right environment play an important role, too.

This view that children have 'domain specific' (Scruggs, et al., 1986) tendencies is controversial. Some educators believe that all students have equal ability in the

eight types of intelligence and, for whatever reason, one of those intelligences becomes more developed than another. Others believe that one particular type of intelligence may have much more potential for development than another and so the child develops greatly in that one and not so much in the others. In his book *'Do Howard Gardner's multiple intelligences add up?'*, John White (1998) severely criticises Gardner's theory of multiple intelligences, stating:

"It seems to rest at root on the insecurest of foundations, dependent on subjective judgements on Gardner's part."

White blames Gardner's weaknesses on the 'shaky foundations' of Piaget's developmentalistic approach and Goodman's theory of symbolism. Goodman's theory of symbolism moves on from Piaget's sensorimotor stage of development, encompassing many symbolic systems such as language and mathematics.

White also argues, quite vociferously, that Gardner cannot justify using his criteria to select what does and does not constitute an intelligence, especially when Gardner (1983) again states in *Frames of Mind* that *'...the selection or rejection of a candidate intelligence is reminiscent more of an artistic judgement rather than of scientific assessment'*.

Despite this debate and controversy surrounding multiple intelligences theory, I will be accepting that it *might* be significant and *might* have some effect on how

well students work, regardless of Gardner's mental architecture surrounding its coming into being or White's criticisms on why it should be rejected.

The area of great interest to physics teaching is the logical / mathematical intelligence. Certain strategies can be used, according to Gardner's theory, to help develop this intelligence in students.

According to Gardner and Smith (1998), mathematical and logical intelligence allows students to produce non-verbal solutions to problems, discern patterns in relationships, manipulate abstract symbols and formulae, understand concepts of time, space, cause and effect as well as being logical and ordered in their thinking.

To develop this type of intelligence, students need to be encouraged to estimate, predict and hypothesise, solve demanding problems, brainstorm ideas before attempting to solve a problem and use metacognitive techniques to describe their thinking throughout a particular problem.

As part of my research, the area of concept mapping has become an important technique, and, despite the controversial nature of the theory of multiple intelligences, I do believe that using certain strategies to improve this 'intelligence' will be very beneficial. If Gardner's theory is correct then it would be possible to assume that utilising his ideas may augment learning and help students to understand the most difficult concepts. A discussion of how this will be done will be explained in subsequent chapters.

Kibble (1999) and Tao (2001), despite not referring directly to Gardner's work, have argued that teaching multiple solutions to physics problems could have a positive effect on the learning of physics material in the classroom. Kibble gave

his students a physics problem to solve and noticed that there were a number of ways in which it could be solved involving graphs, ratios, simple reasoning and algebra to name just a few. Tao asked his students to approach two problems involving mechanics and electricity. Tao noticed that there were four different, but equally effective, solutions expressed for the mechanics problem and three equally good solutions offered for the electricity question. Teaching to meet the needs of students, therefore, might involve more preparation. Teachers are often guilty of delivering the material that needs to be learned via their way of thinking and this will not necessarily match the learning style of the students. Multiple intelligences and multiple solutions may offer access to a greater width of teaching which might incorporate all learners' preferred styles.

5. Mathematics.

Mathematics is a fundamental tool in physics education. Without mathematics, much of the physical world could not be explained effectively. However, mathematics can have a very unsettling effect on some students, because they convince themselves that they 'cannot do' the maths. Previously in this chapter, the mathematical nature of physics was discussed via Johnstone's model of multilevel thought and he called this area 'symbolic' knowledge. In this section, I will now look at research concerning how the brain manipulates mathematical data, how problems may occur in the use / learning of mathematics and make preliminary suggestions as to how such problems may be overcome through teaching strategies.

According to Butterworth (1999) the brain is organised into different specialist regions. Many theories have been put forward as to the brain's structure having different sites for abilities such as reasoning, spacial awareness, memory for general knowledge and linguistic ability. Butterworth's research has shown that much of the mathematical functions are situated in the parietal lobe area of the brain and this may be overdeveloped in some learners and not so much in others, leading to mathematical difficulties.

Butterworth describes how the brain uses three types of memory system which each have their own particular location in the brain. The three types are known as long term memory, semantic memory and short term memory, which is the same as working memory. The long-term memory is the memory that Butterworth refers to as 'autobiographical' memory. We use this to remember when and where we did things in our lives and where they fit into our lives in sequence. 'Semantic' knowledge is another aspect of long-term knowledge that is used for general knowledge and is used for storage of the material we have learned as part of our school-based education. The third area, working memory, allows people to handle a small amount of information, about seven digits or six words, during a small period of time, such as 2 seconds. Without rehearsal, this information is lost and not recorded in long-term memory.

The important question that Butterworth (1999) asks is:

'In which of these memory systems do we store our knowledge of numbers?'

To investigate further, Butterworth studied the numerical abilities of severely amnesic patients (Delazer, et al. 1996). Butterworth and his team noted the following:

Retrograde and anterograde patients (those patients who experienced difficulty remembering before or since their onset of amnesia) performed as well as normal, non-amnesic students when given simple arithmetic problems to investigate. This seemed to show that there is very little connection between this type of long-term autobiographical memory and the performance of simple mathematical tasks. However, when the researchers used a method called 'priming', the results were quite startling.

Priming is a technique where students are asked to solve a number of different simple arithmetic problems, for example, 6×4 or 3×7 , etc. The first sum, of the same type, in a sequence is called the prime. The theory states that the student should be able to answer the sum (the target) more quickly, the next time they see it in the sequence. So, a typical sequence could be: 6×4 (prime), 3×7 , 5×2 , 8×1 , 9×3 , 2×2 , 6×4 (target). Having carried out this research, the team found that despite the amnesics being able to correctly answer the problems, when asked to say whether they had seen a sum more than once, they were only 31% accurate.

Conversely, the control group could state that they had seen the same number twice with 91% accuracy. Both the control group and the amnesic group produced answers to targets that were quicker than answers to primes.

As Butterworth states: “ *This shows that arithmetical facts can be well preserved in the long-term semantic memory of amnesics; they are not ‘amnesic for arithmetic’*”. The research also reveals that problems concerned with simple arithmetic provoke the same mental operations in the brains of normal people as they do in the brains of people with severe amnesia, with the only difference being that amnesics cannot remember whether they have just seen the problem or not. This suggests that long-term autobiographical memory has little to do with stored numerical knowledge.

In terms of long-term semantic memory, research shows that long-term general knowledge is severely impaired, but mathematical problems, involving simple arithmetic, can still be solved. An example of the damage caused to the semantic memory would involve a disease such as Alzheimer’s disease. In one case where a patient had such a disease, the semantic memory was affected, but there was little affect on the solving of simple arithmetical problems. In another study (Remond-Besuchet, 1998) a patient with a severely affected semantic memory could still perform calculations at ‘prodigy’ level.

The working memory’s effect on arithmetical ability is determined by studying how somebody with a poor working memory can handle problems involving simple arithmetic. Research carried out at the National Hospital for Neurology and Neurosurgery showed a particularly interesting result. When asked to repeat

numbers back in a particular order, one patient could manage no more two numbers before becoming confused, missing out numbers or reciting them back in the incorrect order to which they were given. However, when asked to perform mental calculations, the patient could quite comfortably handle questions such as $128 + 149$ and $119 - 35$, which were well beyond his working memory span, placing the man in the 63rd percentile of the population. This would tend to suggest that the loop has a marginal role in the ability to perform arithmetic. The suggestion here (Butterworth, et al. 1999) is that instead of the patient using the normal verbally coded short-term memory to remember and manipulate the answer, he is using a special-purpose memory that is dedicated to mathematical tasks.

The patients who took part in the studies carried out showed the following:

- 1) Independence of number and language.
- 2) Independence of number and memory.
- 3) Independence of number and reasoning. (Butterworth, 1999)

These results would appear to conflict with previously held perceptions that there must be connections between the brain's linguistic, mathematical and reasoning abilities. Some studies, such as those above, have shown that this need not be the case and that there is not necessarily an interconnection.

If these statements are true, then the next question is 'how are the number circuits arranged in the brain?' There is much evidence to show, from studies of brain

architecture, that despite the number-related tasks using the same systems with other processes, the **left parietal lobe** can be seen as a major area of importance. Studies have found that patients with other brain areas damaged, who had problems with skills such as reasoning and language, still had the ability to perform arithmetical problems if their left parietal lobe was undamaged.

The evidence that the mathematical brain resides in the left parietal lobe has been determined via positron emission tomography, a technique where a radioactive isotope of oxygen is used to produce positrons which can be ‘cleverly detected’ and used to show which part of the brain is being used in an arithmetical exercise.

Despite this research into how mathematics and the brain are linked, via the left parietal lobe, being important psychologically, the only importance to my research is that different people do have different arithmetical abilities based on brain architecture. I accept that mathematics is an important reason as to why physics can be difficult and I also accept that the brain’s structure will be an important reason as to why this is the case. However, research into the connection between why students find certain things difficult in physics and detailed brain structure would be well beyond the scope of this research. I believe from my reading that there is a physiological neural difference between those students who have a talent for mathematics and those students who do not and I would still feel that it is necessary to investigate how working memory and its overload can be a main problem in the learning of difficult concepts in physics.

Despite this slightly ‘gloomy’ notion that the left parietal lobe solely determines the extent to which the brain can handle mathematics, much work has also been done in trying to improve the performance of students’ mathematical abilities in areas such as A-level physics. Studies by Andrew Raw at his 11-18 school in Hertfordshire have shown that using an algorithmic approach to teaching A-level physics students who have difficulties with the maths content worked well (Raw, 1998). Based on work by Shayer and Adey at London University and research performed in South Africa (Mehl, 1985) Andrew Raw devised a technique to try and improve the mathematical abilities of the students he taught. As Raw said himself: “ *I was therefore looking for another strategy to improve the students’ learning. I had also been frustrated at times in my inability to explain to students and their parents ‘exactly’ what their problems were and how to remedy them.* ”

Basically, Raw’s approach was to study why pupils who had achieved relatively low GCSE mathematics grades were finding the physics at A-level so difficult. The previous work conducted by Mehl showed that students, when asked to tackle a physics problem at A-level, had no great difficulties with the physics principles involved, but they did have problems concerning the problem-solving aspects of the problems. It may be possible to understand the physics content, but deciding upon the correct physics process to adopt is another matter.

The contribution made by Raw:

Raw’s approach, based on Mehl’s work, was to adopt an algorithmic approach, where particular strategies were laid out to students in a ‘step by step’ format. For example, a problem involving the independence of vertical and horizontal motion

may be split up into a number of steps that contain the ‘important’ transitional steps involved in the complete answering of the problem.

The important aspects of the approach used by Raw and Mehl are:

- 1) The explanation of the topic was more explicit than normal and the thinking needed to solve the problem was broken up into easier ‘chunks’.
- 2) Each topic was broken up into algorithmic strategies based on the nature of the topic, e.g., Newton’s third law, calculation of moments, resolution of forces, etc.

The strength behind this approach is the attention paid to detail of the problems experienced by students, but, of course, it takes a huge amount of time to apply to the whole curriculum and it may well detract from the content part of learning where facts need to be ‘placed’ into the heads of students before the deadline exam date. The emphasis placed on the algorithmic style adopted by Mehl and Raw is, in my opinion, commendable, since direct attention is being focused on specific problems that may need specific solutions as opposed to the general ‘one strategy fixes all’ approach often adopted by teachers, myself included!

The contribution made by Kibble.

To add to the work conducted by Raw and Mehl, further work has been carried out by Bob Kibble concerning how physics / mathematics problems are ‘visualised’ by his students who are studying for their PGCE at Edinburgh University. In his paper, ‘How do you approach a physics problem’ (IOP, 1999),

Kibble states how his ‘problem of the week’ was set to his students to see how they would tackle it. One particular problem is listed overleaf and was taken from the ‘Minds on Physics’ group based at the University of Massachusetts. Dufresne et al. (1997) suggest that the analysis and interpretation of a problem is performed by associating the problem with different pieces of knowledge. Such associations can be mathematical, pictorial or conceptual (Kibble, 1999) and they determine how much is learned from the problem-solving process.

The problem (Kibble, 1999):

Janet and her brother John decide to race along to the end of the street and back again. The street was 80 metres long. Janet ran at 2.5 ms^{-1} and John’s speed was 1.5 ms^{-1} . Where were they when they passed?

Some students solved the problem using algebra by comparing the distance travelled, shown mathematically as: $X/1.5 = [80 + (80 - X)]/2.5$, giving $X = 60$ metres. Some students solved the problem by drawing a displacement-time graph, some students solved it by looking at relative speed and, finally, some students attempted the problem by looking at ratios. Whatever the approach adopted, the students managed to obtain the same answer each time.

Kibble’s ‘lesson’ from this is that the lecturer’s preferred method for solving the problem is not necessarily going to work for all students. Mathematics, it would

seem, is an individual thing and needs to be addressed. From personal experience, I would much rather solve a problem using algebra than attempting it by ratios. As Kibble states:

“ It is clear to me that I should look for alternative ways of solving problems simply to offer solace to those pupils who approach problems with perspectives other than mine. For them, I am sure that their self-esteem is dented when they see that their teacher’s method is different from their own. There is a hidden weighting to the teacher’s route virtue of its originator.”

This possible mis-matching between teacher’s method and student’s desired method could be a reason why difficulties are experienced in the learning of physics. Admittedly, the level of difficulty, as shown in the above problem, is far more demanding than many calculations expected at GCSE level, but the principle of mismatch does still apply.

One particular difficulty experienced at GCSE level is a standard calculation involving the conservation of energy. Basically, students are asked to calculate the gravitational potential energy of a diver at the top of a diving board and, by assuming it is converted to kinetic energy alone, to calculate the speed of the diver just before he enters the water. The idea of conservation of energy is generally well understood, but introduce the mathematics of $mgh = \frac{1}{2}mv^2$ and ask the students to transpose the equation to find v and they start to experience

difficulties. The research concerning how I attempted to simplify this is discussed in the relevant chapters.

The contribution made by Gill.

The work of Gill (1999) also suggests that mathematics is a major problem in the learning of science. Gill has noticed that undergraduate students struggle with the mathematical content because it is 'decontextualised'. By this comment, Gill is saying that teaching mathematics to many hundreds of students in the same lecture theatre from many different subject backgrounds can introduce problems of its own. Often, the mathematics taught might not be 'clear' to the economics student in the same way that the engineering student sitting next to him might find it. Gill states that there are many problems that regularly appear in the mathematics of calculus (especially integral), logarithms, trigonometry, complex numbers and factorisation and he proceeds to mention the problems that students have with graphs. So remarkable was the difficulty with graphs that Gill could actually predict how well students would do in their final exams based on how well they performed in the isolated graph-style questions.

Coupled with the knowledge and skills-based deficiencies in mathematics, Gill also noticed the metacognitive problems that the students had. As one of Peter Gill's colleagues has stated: '*pupils don't know what they know and don't know what they don't know*'. Most of the pupils that Gill interviewed said that they did not see learning as an 'active' process, more of a passive approach where knowledge was added to their heads in the jug model of learning. When asked

about their beliefs concerning the relationship between maths and physics, the students, unanimously, stated that they thought there was no connection between the two at A level or at degree level! One student quoted: '*...we haven't used much maths in physics much*', which, as Gill states, is a comment that '*raises questions about what they think maths actually is*'.

Gill uses Entwistle's (1987) model to show three approaches that students use at university, which are:

- a) The **Deep** approach;
- b) The **Surface** approach,
- c) The **Strategic** approach.

The deep approach involves the student trying to understand the new work and relate it to existing knowledge, producing a well-rounded and effective new knowledge. Gill states that this new knowledge will be holistic and integrative in style. The surface approach is when the student merely tries to 'cope' and memorising the material is used far more frequently than trying to understand the new material. The task itself is not seen as being directly connected to other areas and so the learning is 'atomistic' and 'piecemeal'. The strategic approach is where the student tries to achieve the highest grade and this approach involves studying past papers and mark schemes.

Gill goes on to state: *'...the strategic approach is often institutionalised. The attitude of physics and engineering departments often seems to be that the mathematics course is a hurdle for the students to overcome, not an integral part of the degree course.'*

Gill summarises his findings in three ways. Firstly, students often enter university not being able to cope with the maths. Secondly, students enter university with fewer skills than they need. Thirdly, students who do know the maths cannot use it in the correct context, which is certainly not a new problem and has been referred to in the past via 'transfer of training'. Gill's final statement is that if students learned the mathematics then they would be able to apply it in novel situations. The observation that mathematical erudition is probably worse now than it was twenty-five years ago is something that Gill thinks can not be sorted out through 'moaning' but via constructive discussion at all levels.

6. Language-based Phenomena:

The final area of this chapter addresses the possible role played by language in the learning of physics with special interest paid to why language might make the physics at GCSE and A level difficult to understand. One possible suggestion is that certain words are relics or 'fossils of old thoughts' (Sutton, 1992). Many words, not in common or mundane usage, are used in physics with particular, technical meanings that can be easily misinterpreted. For example, the word 'satellite' means, at the GCSE level, 'a body of smaller mass that travels around

an object of greater mass due to the force of gravity'. However, the word 'satellite' comes from the Latin word 'satelles' which means 'attendant'. Galileo observed these moons around Jupiter and Kepler named them as satellites as though they were 'attendants on a more important person'. We confuse our students now with terms such as natural satellite, weather satellite, geostationary satellite, and, most famous of all, satellite television. It is hardly surprising that many students are confused when asked to describe what a satellite is: the moon, the metal box bouncing signals back from space or the dish on the back of the house! The major problem is that language can be introduced into a lesson without spending sufficient time on explaining its definition, its origins or its possible ambiguities or clashes with the same word used in other subjects.

As an example, the word 'solution' has a different meaning in chemistry as it does in mathematics. The word 'latent', unless explained thoroughly in physics and related to its normal usage definition of 'hidden', could leave pupils with no understanding of thermal physics at all. The word 'conductor' means a different thing in physics than in music and the word 'salt' is enormously different in chemistry than in common usage.

As well as these ambiguous problems, there is also a problem with the unfamiliarity of new words. As part of the GCSE syllabus, pupils need to become familiar with such terms as: **momentum**, **centripetal** force, **protostar**, **virtual** image, **terminal velocity**, **convection**, **moment**, **decommissioning**, **fission** and **fusion**, etc.

All of these words have definite meanings in physics and they need to be understood as qualitative definitions or as mathematical formulae. It is the vocabulary of science that is often forgotten about in terms of the difficulty that it may cause students in place of the more obvious mathematical difficulties associated with the physics syllabus. I chose to investigate students' understanding of relevant physics vocabulary as part of the preliminary research model and this is mentioned in the preliminary research chapter. In performing this, students were given a questionnaire on which they were asked to indicate their understanding of potentially difficult, unfamiliar or ambiguous words used in their most recent topic studied. These areas were Forces and Motion (Year 10), Energy (Year 11) and Further Physics, Astronomy and Optics (Year 13).

As well as difficult words which are used as part of the physics **content**, there are also potential problems with words concerning the physics **process**. Students at GCSE have a compulsory coursework component worth 25% of their final GCSE mark. As part of this work they have to be familiar with terms and concepts such as: **planning, predicting, hypothesising, analysing, evaluating, theory, observation, anomalous results, validity, reliability**, as well as others. There is no surprise, then, that students can find this aspect of the investigative side of physics extremely difficult.

When questioned about this side of the investigation process, most students could not tell the difference between validity and reliability and very few understood how an analysis was different from an evaluation. This is not the fault of the

students, but is a major concern to pedagogy since the ‘nuts and bolts’ of science process are as important as the ‘framework’ of science content.

7. Confidence and metacognitive self-regulation.

The confidence of students is an aspect of learning that only became apparent relatively recently in this research period. Students of low ability have often been seen to be the ones that suffer from lack of confidence and the associated behavioural problems that appear to stem from this ‘frustration’ (Emerick, 1992) maybe exacerbated by their own envisaged ‘failings’. When students were tested, during lessons or during end of module tests, they were asked to use a ‘certainty of response index’ (CRI) to help show themselves and myself how confident they were of choosing the correct response for a question. This CRI idea (Hasan et al. 1999) was used to help monitor students monitor how accurate they were at getting the correct answers in a test. This is useful because it gives students an insight into their own mental processes, conceptions and misconceptions, it helps them to become metacognitive and it works as an efficient tool so that students can effectively filter out the material that they do know from the material that is causing them difficulty. Metacognitive reply sheets, developed by myself, can also be used to allow students to make explicit what their opinions are about themselves as learners, the teaching, the course and other areas where difficulty may arise. These all help to build better schemes of work and more confident learners.

Summary of Chapter:

In this chapter, the research concerning ‘why’ certain aspects of physics are seen as more difficult than others was addressed. These areas will now be summarised and how they will be applied will be discussed in the methodology chapter.

- 1) **Working memory** can only store a certain amount of information at any one time. This can be ‘overloaded’ by the delivery of too much material in too short a space of time. Working memory is a different model from short-term memory since it involves the processing of information through the articulatory loop, visuo-spatial scratch pad and the central executive. Both the short-term memory and working memory are believed to have a limited storage capacity that is ‘fragile’ since distraction can cause processing to be affected and storage to be disrupted (Gross, 2001).
- 2) The **nature** of science material itself is difficult, especially if it **symbolic** or **sub-micro** knowledge. Easier areas are **macroscopic** knowledge, which are visible and tangible.
- 3) Multivariate processes, or **formal** operations, are more difficult than concrete, or bivariate, processes (Piaget) because of their greater cognitive demand. Adey and Shayer (1981) both state that concrete operations generally involve imposing a structure on reality, whereas formal operations involve looking at reality and then trying to see how a set of

independent rules and assumptions concerning this reality actually correspond. For example, a concrete thinker will have difficulty when trying to differentiate between the ideas of heat and temperature. Heat and temperature at concrete level may 'collapse' into one single piece of understanding. Conversely, a formal thinker will be able to explain the ideas of heat and temperature in terms of energy and, eventually, via a comprehensive understanding of the first law of thermodynamics. The function and goal of thinking skills strategies is to try and promote students from the concrete stages into the more sophisticated formal stages.

- 4) **Multiple intelligence and multiple solution** research suggests that some students have a preferred learning style which may, or may not, help them when learning a subject such as physics. Students generally thought that providing information in a number of different ways was useful as it gave them another way of looking at the problem. Different multiple intelligences tend to have different learning attributes associated with them. For example, an *interpersonal* learner has a different mindset to a *logical* learner. Pupils might also need to be shown more than one way of tackling problems in physics. This will allow students who attempt questions in different ways to 'share' skills and improve their learning repertoire. Students generally thought that multiple intelligences theory was interesting but not as useful in a pedagogical fashion as the multiple solutions theory provided by Kibble and Tao.

- 5) **Mathematics** is seen as a major problem for a number of reasons. Three pieces of research show that mathematics is difficult because:
- a) its symbolic nature is hard to visualise and it overloads working memory;
 - b) the **left parietal lobe** region of the brain determines our mathematical ability and is independent of autobiographical, semantic or short-term memory.
 - c) Students find it difficult to understand and difficult to apply to new contexts. Some students even see it as being unconnected with physics.
- 6) **Language** is, potentially, a difficulty as the vocabulary can be ambiguous or its origins can be unclear. Two areas of difficulty are words or terms associated with physics content and with physics process. Problems also occur because the pupil's understanding of scientific knowledge conflicts with public understanding or metascience. Since much of the vocabulary used is also quite polysyllabic it might take up too much working memory space for it to be learned effectively. The words used regularly in physics education such as evaluate, anomalous, hypothesis etc. are often new and poorly understood, making it difficult to apply. Introducing this language at a younger age, or simplifying vocabulary, could solve this problem.
- 7) **Confidence and metacognitive self-regulation** is an important area and studies have shown that there is often a discrepancy between students' opinions of themselves and teachers' opinions of students. Confidence

plays a critical part in the education of students. Metacognitive processes and strategies can be used to help students monitor their own performance, with the end result being improved performance and self-confidence. Students in the study were familiar with some metacognitive techniques and the certainty of response index (CRI) was used regularly so that students could monitor their performance and vocalise their feelings, something which they had never been used to in previous lessons. Hopefully, students can express their feelings of success and failure via metacognitive strategies so that their misconceptions or low self-esteem can be remedied. Although some literature stated that it is often low-ability students who find themselves with low self-esteem, other papers have stated that the opposite is in fact true, with many highly able students possessing feelings of inadequacy. There is an academic and a moral need for this to be modified so that students can maximise their self-confidence, their understanding and their examination performance.

Chapter Five

Tackling Difficult Concepts in Physics using Thinking Skills

Approaches

In this section, the main findings of the preliminary research will be reviewed and their relative importance will be discussed. From these initial findings, the actual thinking skills programme that will be used in the research will be explained, based on the initial findings from the preliminary data. As a reminder, the six main items that were researched in the preliminary section are listed below:

1. Working memory
2. Macrophenomena/ microphenomena/ symbolic knowledge
3. Concrete and formal operational thought
4. Multiple intelligences
5. Mathematics
6. Language and vocabulary
7. Confidence and metacognitive self-regulation.

Each of these items needs to be discussed. It is important that the initial findings allow the subsequent research to focus on the most appropriate areas of the research. There is a need to use the preliminary research to determine the essential elements of the main

research and to eliminate the areas of the preliminary research that are less important or superfluous.

The findings of each of the six items will now be discussed in depth and the findings will be used to help construct the thinking skills programme.

Working Memory:

The preliminary research showed that the working memory model was potentially very significant. Students were given tests to see how their ability to recall different lengths of numeric characters compared with one another. A fixed set of numbers were recorded onto audiotape and then played to students. To ensure fairness, the numbers used each time were identical and the time between numbers was kept constant by using an electronic metronome. The working memory model was used with all of the classes in my school and the tape was also given to teachers at other schools for them to use with their students.

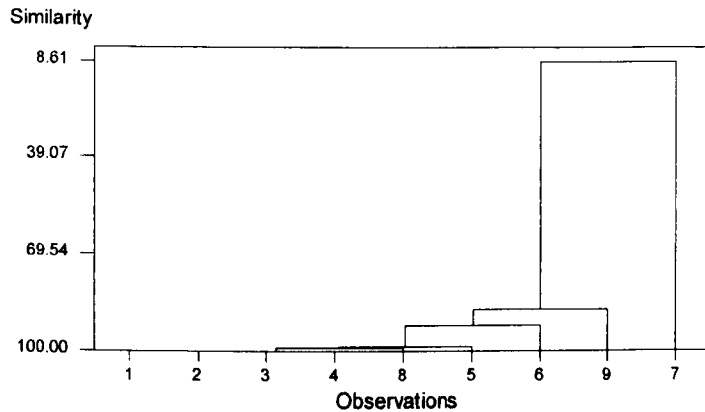
The process of data collection involved explaining to the students the following points:

1. Why this was being done (i.e. for research)
2. What they had to do
3. The confidentiality issue (no names)
4. The fact that no numbers could be repeated, i.e. the tape could not be replayed
5. The need for complete silence.

The numerical data that was 'dictated' to the students consisted of nine sets of numbers, ranging from four digits in length to nine digits in length. Each student was given a length of time, fixed at 25 seconds, to try and remember the data and then write it down in the same order in which it had been dictated.

The results obtained from the preliminary working memory model data were extremely good. By using cluster analysis and dendrograms, the statistical methods showed that the responses given by students were close to 90% accurate for numerical strings up to six digits in length. Seven items of information appears to be the stage at which there is a 'departure' from the comfortable memorisation of numerical data. At nine items, there is less than a 10% similarity between the mentally recalled data and the actual data that was delivered containing 7 items. This shows that the Miller's 'chunking' model, where data can only be successfully manipulated in the working memory, is only effective up to about seven items. At nine items there is a massive decrease in the effective 'immediate' recall of data. These findings would also be consistent with the working memory work conducted by Baddeley and Hitch (1974) in their groundbreaking research on working memory.

Fig. 5.1 Dendrogram showing percentage similarity between number strings used in a working memory exercise, during the preliminary results episode.



The findings from the statistical analysis were then further investigated via questionnaire. The questions on the questionnaire pertaining to the ‘chunking’ and working memory aspects of the research were as follows:

1. To what extent do you agree or disagree with the findings from the chunking investigation?
2. Do you think that there is anything educational that could be learned from the results of the chunking investigation?
3. Could the findings have any impact on the way that physics is taught? If you think that the findings suggest strategies then what might these be? If, however, you feel that the results are not significant then say why you think this to be the case.

The general pattern was that students found that the chunking model, despite being simplistic, did have credibility. 94% said that they agreed with the idea that too many numbers do tend to overload the memory and 86% also commented that this applied to non-numerical data in lessons. Quite often, students commented that the pace and duration of a lesson tended to overload their memory and was counterproductive. One student (Code: SHS21) commented:

'Despite the best efforts of teachers and students, the content volume and rigour of an exam course, with the added strain of self-imposed pressure for success, can be quite overwhelming. Sometimes we all just want a break! Too much, too soon can do me more damage than if I did it in 'bits', and I like it better when we review the work at the end of the lesson or when we do short but regular tests. Then I find that the pieces fit together in neat chunks, rather than one big sprawling mess. The modular approach makes this easier and I like the manageable chunks of modules. I wouldn't like it all the time, though, as too many tests make it boring and you need to 'spice it up' with some practical work and other types of learning that we get to do.'

In order to use students' opinions and comments as a constructive part of the thinking skills programme, it was necessary to produce a list of 'students' requests' from the questionnaire. The top five requests that students asked for based on the findings of the chunking data results were:

1. Summarise the learning objectives before the lesson starts, no more than 'a few'.
2. Use short, regular tests to test knowledge during lessons or at the end of every lesson.

3. Don't teach/dwell on the same area for more than 15 (mean value) minutes without a complete break.
4. Allow or encourage students to shout for 'help' when the teacher goes too quickly.
5. Repeat the regular tests, added small numbers of 'new' questions each time.
6. Highlight or emphasise key words, rather than superfluous text that takes up room.
7. Use key words only to build 'small' concept maps of no more than seven items.

These results were obtained from year groups 9 to 13 and the most 'valuable' and coherent responses tended to come from the GCSE and AS/A2 who were most familiar with the stress of exam preparation. Many students commented on the perennial problem of sheer volume of information and the chunking model was accepted by the older students as being a possible remedy for this. Younger students, despite commenting that it might be useful, could not explain how the chunking data results could be used for implementing a more 'effective' curriculum.

Having obtained a large amount of preliminary data on chunking (N= 60), the overall significant findings were:

1. There was a sharp drop in the ability for accurate recall at around 7 digits length and this applied to many of those students in the sample.
2. There was a connection between the ability to recall large strings of numbers and the examination scores obtained by students in their most recent examinations in physics. (Correlation = 0.509, p-value = 0.001).

It was accepted by myself, based on background research, and by the students in my school and other schools that a set of new thinking skills style strategy could have an advantageous effect on the learning and recall of physics material. In particular, those strategies that would be implemented would involve the highlighting of keywords in text, the construction of small concept maps and the regular use and repetition of small tests which would eventually build knowledge by helping to commit familiar chunks to long term memory. These ideas and strategies, which are driven by the engine of 'metacognition' as a fundamental thinking skills tool will be discussed in more detail at the end of this chapter, once the other preliminary findings have been presented and their relative potential contributions discussed. In particular, the nature and structure of the strategies will be explained based on the theory and findings.

Macrophenomena, Microphenomena and Sub-micro Phenomena.

The preliminary research showed a number of important results concerning macro, micro and symbolic knowledge. In order to test the relative difficulties of the macro, micro and symbolic forms a number of questions were set. Students were given questions from a number of areas of the GCSE and AS level syllabuses. Each question was split into three parts, which were macro, micro and symbolic in nature, and each part of the question was worth five marks. Having collected the students' answers, the questions were marked and the total number of answers (N=204) were analysed, quantitatively, using a statistics package. The main findings are as follows:

1. Macro knowledge (tangible, easily visible, everyday knowledge) was generally accepted as the easiest of the three types of knowledge. Students from year groups 9 to 13 ($N = 68$) who were tested on the three types of knowledge tended to find this section by far the easiest. From the preliminary research data, 50% of students questioned found macrophenomena style questions the easiest and 18% stated that they found them the most difficult.
2. Symbolic knowledge (knowledge involving symbols, formulae, mathematics, symbolic representation) was found to be highly variable dependent on the nature of the question. In terms of the mathematics, the scores obtained in the various questions were highly dependent on the nature of the mathematical technique or techniques involved. Those questions involving mere mathematical substitution were often found as easy, if not easier, than the corresponding macro question. Conversely, mathematical questions where a formula was not provided and students had to formulate their own thinking were found to be much more difficult and scores for these were often close to zero marks out of five. However, some questions where a formula was not provided did also provide relatively high marks. When questioned further, students stated that the reason why they found certain questions easier than others when a formula was not provided was based on their ability to make the question 'macroscopic'. In other words, some symbolic questions could also be quite 'macro', making them relatively easy, whereas some questions were difficult to visualise and understand making them quite 'micro', hence augmenting the students' difficulties. Questions that were

purely symbolic were found to be the easiest by 5% of students and most difficult by 51% of students.

3. Sub-micro knowledge (invisible knowledge) is the knowledge that the students found by far the most difficult. When asked to give answers to problems that were highly intangible, such as thermal processes, energetics, electrical conduction processes, nuclear fission and fusion, students' answers were often lacking in detail, understanding and the correct physics. This was increased when mathematics or other symbolic forms accompanied a sub-micro question. Purely symbolic style questions were found easiest by 45% of the students and hardest by 31% of students.

As an example of the data collected, here is a selection of the types of questions asked in each of the fifteen mark tests that were administered. As explained, there were three sections, each worth 5 marks. Each question had a mark scheme, written to coincide with whether the section was macro, micro or symbolic. Here are relevant examples, from the GCSE section:

Macrophenomena:

1. Name the seven colours of the visible spectrum in order.
2. Why do we experience day and night?
3. What changes could you make to a circuit to make a bulb brighter?
4. What would you see happening at the electrodes during the electrolysis of copper sulphate?

5. Explain how a seesaw can be made to balance. Draw a diagram to explain your answer, but do not use any equations.

The examples above are intended to focus on the tangible aspects of science that can be seen and explained without any major 'insight' or use of mathematical modelling.

Microphenomena:

1. Explain why your hands get hot when a metal rod is heated at one end and you are holding the other end.
2. Why does the resistance of a wire increase when the wire gets longer? Use your ideas of current and charge flow in your answer?
3. Explain how we can use uranium to produce electrical energy for distribution via the national grid.
4. How is an adiabatic system different from an isothermal system in terms of the energy transfer?
5. How is boiling similar to and different from evaporating?
6. Does sound travel faster in air or glass? Explain your answer.
7. Explain what happens to temperature when water at 100degrees Celsius condenses and is then made to freeze, by referring to its atoms.
8. Explain why waterfalls do not flow upwards by referring to entropy.

Symbolic Knowledge:

1. If the size of the centripetal force acting on a piece of metal being swung in a circular orbit is given by $F = mv^2/r$, then find the size of the centripetal force when $m = 3\text{kg}$, $v = 5\text{m/s}$ and $r = 2\text{m}$.
2. Find the size of the resultant force acting on a body of mass 45kg that is accelerating at 3.5m/s^2 .
3. If a mass of 35kg balances a ruler when placed 2.5m from a central pivot then find the mass needed to balance the pivot when placed at 3.6m on the other side of the pivot.

These examples of macrophenomena, microphenomena and symbolic knowledge questions are intended to be fairly 'pure' in their design. It is possible to have questions that are virtually completely macrophenomena style questions, completely microphenomena style questions or completely symbolic style questions.

The main difficulty experienced by students was found to occur when questions became mixtures of two or more styles of question. For example, students were very comfortable answering questions that were purely symbolic. In other words, questions that just involved symbolic representation of simple ideas or simple mathematical manipulations were generally well answered. However, questions that involved two skills to be applied simultaneously were found to be very difficult, resulting in low marks. In particular, the most difficult questions were those that involved microphenomena and symbolic knowledge.

As an example, here is a selection of different styles of question that incorporated two or more of the three styles of knowledge :

Table 5.1: Macro/micro/symbolic composite question examples.

Style of Question	Question example	Comments and Findings
Macro-Micro	Explain why a puddle of water can be made to evaporate on a warm, windy day by referring to kinetic theory	Many students could handle the kinetic theory idea because of the tangible macro nature of puddles being seen to disappear. Mean mark was 2.8 out of 5.
Macro-Symbolic	A pendulum has a time period given by the equation $T = 2\pi(l/g)^{1/2}$. Use this equation to work out the time period for a pendulum of length 2.5m. Show what happens to the time period when the length doubles to 5m, by using the equation.	Most students gained above half marks. Substitution of values was easy and comparison of time periods based on lengths was also well performed. Mean mark on these questions was 3.0 out of 5.0.
Micro-Symbolic	Calculate the de Broglie wavelength of an electron travelling at 45% the speed of light and explain whether diffraction will occur when it passes through a gap of 1.4 Angstroms.	This was found to be extremely challenging to all but the best students. The invisible nature of the physics and the added difficulty of mathematics that made little sense caused problems. Mean mark was 1.2 out of 5.0.

As shown, the submicro level of physics content, in conjunction with a need for mathematical analysis, caused enormous problems. When interviewed, many of the students stated the following difficulties:

1. The micro-symbolic problems could not be visualised, no matter how much the students tried to 'see' the problems.
2. The physics involved was extremely difficult to accept.
3. The mathematics did not 'make sense' on a mundane level. For example, how could a particle be a wave and why does that lead to a weird equation?
4. They did not 'trust' the physics. For example, some students said: 'how do we know that this is right? What we learned at GCSE seems to be all wrong, and who is to say that de Broglie is right? If I cannot see it then I cannot trust it.'
5. The terminology used confused students. Many sub-micro level questions at GCSE and A level needed to include the more 'hidden' aspects of physics such as diffraction, wavelength, inertia, kinetic theory, isothermal and adiabatic systems, charge, momentum, torque, electromotive force and centripetal force. The problems involved the vocabulary but, more importantly, the problems were exacerbated by the need for an understanding of how the terms were connected in terms of mathematics and fundamental laws of conservation. Despite the fact that many students could explain what momentum was, very few could apply laws of momentum and energy conservation to problems and even fewer could explain how kinetic energy

was conserved or not conserved depending on whether the collision was elastic or inelastic.

The preliminary research into Johnstone's model of knowledge, as well as the subsequent interviews that have been conducted, did show that there was a high agreement between students on what was perceived and found to be very difficult. A strategy to overcome the problems associated with submicro work will be included in the thinking skills programme that will be used in the main research and this will be discussed at the end of this chapter.

Concrete and Formal Operational Thought

Concrete and formal operational thought are two important aspects of thinking skills packages, such as CASE, the package used in secondary schools, developed by Shayer and Adey at London University and based on the work of Jean Piaget.

In secondary schools, the two major types of thinking are concrete and formal, although these can be divided into early and late stages respectively. In simple terms, virtually all children of secondary age reach the early concrete stage of thinking, whereas few (about 20%) reach late formal operational thinking at the age of 16. As Shayer and Adey (1981) state:

" Concrete operational thinking involves putting considerable structure on reality... where its rules are adequate to the situation it is successful. The problem comes when the rules are not adequate... Thus it is being suggested that one important difference between

concrete and formal thinking is the qualitative change in complexity in moving from one independent variable to situations where two or more are involved”.

To overcome this problem of ‘leaving students behind’ at the concrete stage, a thinking skills programme needs to incorporate methods where students are encouraged to observe, design and investigate multivariate problems. This approach is now a well-established part of secondary schemes of work and has been a consequence of the work of CASE. Problems involving multivariate mathematical manipulation and techniques also need to be included in the curriculum at all levels to help move late concrete thinkers into the early formal stage.

As an example of how the four stages differ, see the table below:

Table 5.2: Examples of concrete and formal operational thought thinking stages.

Thinking Stage	Investigation Example	Written work Example
Early Concrete	‘What Floats?’ A student is asked to design an experiment to find out what floats. The result will be that ‘heavy’ things sink and ‘light’ ones float.	“ I think that heavy things sink and light things float”..... “ I think that the more heat something has the greater its temperature will be”..... “ Big cars are faster than small cars.”
Late Concrete	‘How fast?’ A student is asked to find out the speeds of vehicles in the street. The student uses $\text{speed} = \frac{\text{distance}}{\text{time}}$ to find the speeds and then compares them.	“I think that heavy things can float if they have a large size like ships”..... “A large cup of hot tea has more heat than a small cup of the same tea”.
Early Formal	‘What balances?’ A student is asked to find out when objects balance on a seesaw. The student finds that $F \times d$ on one side of pivot equals $F \times d$ on other side of pivot.	“A mass of 4kg when placed 3m to the left of the pivot will balance a 6kg mass placed 2m on the other side of the pivot. This is because the moments balance.”
Late Formal	‘What Volume?’ Student can predict how volume changes when the temperature increases by a factor ‘x’ and the pressure by a factor ‘y’. The student would then plan and carry out an investigation using appropriate apparatus.	“The pressure of a gas remains the same if I double the temperature of the gas by heating it up whilst allowing the gas to expand and occupy twice its initial volume. If I kept the volume fixed, though, then the pressure would double.”

A major desire involving thinking skills packages is that the students at the late concrete stage can be ‘pushed over’ the barrier into the early formal stage. This would mean that students would have to abandon the more egocentric, single-variable description of how they visualise the physical world in operation. It would also mean that they would have to adopt a more objective view of the nature of scientific investigation and leave behind the ‘I think this will happen, therefore it will’ mentality associated with early concrete operational thought. This raises a number of fundamental questions:

1. How do we determine where a student is on the line from early concrete to late formal?
2. How do we get a student at the late concrete stage into the early formal stage?
3. What do we do to keep a student in the formal operational mode of thinking?

To answer the first of the bullet points above, the preliminary research found that, by using standard tests called SRT’s (Science Reasoning Tasks) and other methods of qualitative assessment, the pupils could be placed at stages 2A to 3B quite effectively; this was also reinforced by using other techniques. One such techniques involved asking students to design their own investigation. The instructions that they were given were:

1. Design your own investigation that can be performed safely in the lab.
2. You must list your apparatus
3. You must list the variables

4. You must state how you will make your investigation a fair test
5. You must explain how you will collect your data for analysis.

The preliminary findings showed agreement with the results obtained in this study and previous studies concerning concrete and formal thinkers. Those students who were concrete thinkers could list their apparatus and explain their method reasonably well, but when explaining how they would make the investigation 'fair' there was often an implementation problem that meant that the investigation was performed unfairly. Usually these difficulties were quite subtle, but showed how the concrete thinker differed from the formal thinker. In one particular example, Year 9 students, embarking early on their GCSE course, were asked to plan how much force was needed to move shoes with different soles across a surface such as sandpaper. The force was the force needed to overcome static friction. The subtle difference between the concrete learner and the formal learner was the 'thoroughness' executed in ensuring that the investigation was, indeed, fair. Concrete learners tended to respond when questioned: "I have followed my instructions and kept the surface constant, so the only variable must be the shoe type". This approach can be likened to following a recipe rather than applying a 'metacognitive' approach of continually asking whether the method is truly fair. Conversely, pupils with a more formal background noticed that although *on the surface* the investigation *appeared* fair, that other aspects needed to be addressed to ensure fairness. One student commented: "To make my investigation fair, the shoe type can change but nothing else. This means that I will have to place some masses in some shoes to keep the weight the same as this

may be important.” Some students took this idea further by comparing the surface area of the shoes to ensure fairness.

More background theory about this area is mentioned in chapter four. However, the preliminary research carried out has suggested aspects of the thinking skills programme that need to be implemented. These are discussed below and will be referred to again when the whole thinking skills programme is summarised. The preliminary findings suggest that the following strategies need to be implemented, with direct reference to thinking skills ideas:

1. Investigative techniques need to be clearly demonstrated to pupils because there is a large difference between individuals’ understandings of key ideas such as ‘fair testing’.
2. Metacognitive strategies need to be addressed. Pupils need to be encouraged to keep asking themselves questions pertaining to the way in which they are carrying out their investigation. If problems arise, the pupils need to suggest ways in which their current procedure needs to be modified.
3. Pupils need to be encouraged to ask their own questions relating to all aspects of scientific investigations and the underlying scientific knowledge.
4. Cognitive conflict needs to be incorporated into problems so that students can try to formulate answers that are not just based on opinions but also on scientific knowledge and evidence. It is important to mention at this point that cognitive conflict is dependent on the student *actually attempting* to resolve the conflict. For

many highly motivated students this may not pose a problem and a new concept may be created or, in terms of displacement (Newton, 2000), exist alongside the old concept. However, less motivated students, or students who are 'incapable' of constructing the new concept, may not use the idea of cognitive conflict effectively and so the old, incomplete concept will remain in use. There is evidence to suggest the successes of cognitive conflict (Hynd et al. 1994) and evidence to suggest otherwise (Guzzetti, 1990).

5. Students need to accept when they don't fully understand an area of the work. Problems were found when students were asked to explain an answer and admitted that they 'sort of' understood. Upon further scrutiny the 'sort of' responses were found to be more like 'I really have very little understanding'. In investigations and theory work, pupils need to be encouraged to grade their understanding and, therefore, show themselves when they need to ask for help from an expert.
6. Being placed in unfamiliar situations where the knowledge that students possess can be adapted to try and cope with new problems is an important strategy that should be encouraged. This is known as 'transfer' in thinking skills terminology. Allowing students to have access to these unfamiliar situations should increase their metacognitive skills and open up a 'broader mind'.
7. Students should be encouraged to produce their own questions with mark schemes based on their understanding of a particular topic. This role reversal of 'student asking teacher' will allow students the 'freedom' to express their understanding in their favoured way and will allow the teacher, as expert, the chance to diagnose

and correct any misconceptions in the students' understanding. This method also allows the progress of the students to be monitored.

8. Monitoring confidence in responses when answering questions should be adopted in the testing environment. A CRI or 'certainty of response index' should be written down next to answers when students provide their answers in tests. The findings in the preliminary research showed that there is a positive correlation between how highly students scored in tests and how confident they were in the answers. Again, this has the dual effect of allowing students to apply metacognitive strategies to their thinking as well as allowing the teacher to diagnose which areas of the topic are more demanding. This will help later on when time is needed to focus on revision of the areas that students found most difficult along with which strategies to use to help augment subsequent understanding.

Tackling difficult concepts via Raw's work and ideas.

One recent, and highly significant, piece of work concerning thinking skills is the work conducted by Andy Raw, a physics teacher at a secondary school in the south of England. In his paper "A thinking skills approach to A-level physics questions" (1998), Raw identifies eleven areas that need to be addressed if students are to successfully attempt problems. The work conducted by Raw is based on similar work conducted in South Africa by Mehl (1985).

The areas identified by Raw as being ‘deficiencies’ are as follows:

1. Not reading a problem carefully
2. Impulsivity
3. Blocking
4. Poor visualisation of the problem
5. Unplanned and unsystematic approach
6. Monitoring
7. Motivation
8. Lack of precision in work
9. Difficulty with two sources of information
10. Difficulty in spotting implied information
11. Difficulty in explaining things clearly

Raw, basing his ideas on Mehl’s work, suggests that a more ‘broken down’ and algorithmic approach to attempting questions would benefit many students, especially those who were embarking on an A-level physics course who obtained only a B or C grade at GCSE level. In his paper, Raw suggests an algorithm for solving a mechanics problem that has been broken into seven distinct steps. The seven steps show how students can answer problems where resolving forces into horizontal and vertical components is needed and this algorithm can be seen in Raw’s paper.

As part of the preliminary research, a sample of GCSE and A-level students (N=96) at my school were given questionnaires concerning their opinions on the eleven areas identified as being problematic by Raw in his study. The students were asked to grade on a scale of one to five whether they agreed with these particular statements. The scale used to grade each statement is shown on the next page:

Table 5.3: Responses to Raw's questionnaire.

Response to Statement	Value relating to response
I totally agree that this statement is relevant	1
I partially agree that this statement is relevant	2
I am unsure of this statement's relevance	3
I believe that this statement has little relevance	4
I believe that this statement has no relevance	5

If a student thought that 'Blocking' (mind going blank in exams due to fear of failure) was a definite problem in problem solving then that student would grade it '1'. If, however, a student believed that 'Blocking' was of no consequence in exam technique at all then they would have to grade it as '5'. Once students had been asked to grade these questions they were then asked to arrange a 'league table' of how the eleven statements

applied to themselves in particular. The findings I obtained from the preliminary research are as stated below:

1. The majority of those GCSE and A-level students questioned stated that all of the statements were either completely or partially true, that is, most of the responses were '1' or '2'. It was noticed that some students, particularly those deemed as 'concrete' learners gave low values (1 or 2) for the response 'difficulty with handling two sources', whereas those students deemed to be more 'formal' thinkers tended to give high values (4 or 5) as their response. This needs to be quoted for a number of reasons that are important: firstly, concrete learners will have difficulty in handling two or more sources of data whereas formal thinkers will not; secondly, it shows that concrete and formal learners appreciate their difficulties; thirdly, it shows that a mean value which would seem to indicate 'uncertainty' is actually close to three due to this 'polarised' effect. This was the case for statements 6-11 listed in table 4.4 and it does, unfortunately, show how the actual responses from a polarised group can be concealed by averages.

2. Table 5.4: Mean values obtained for Raw's data using my GCSE students

Statements (In order of difficulty)	Mean Value
1. Not Reading The Question Clearly	1.58
2. Difficulty Explaining Answer Clearly	1.83
3. Lack of Precision	1.84
4. Motivation	1.92
5. Impulsivity	1.96
6. Blocking	2.08
7. Monitoring	2.13
8. Poor Visualisation of Problem	2.33
9. Spotting Implied Information	2.42
10. Unplanned Approach	2.54
11. Difficulty Handling Two Sources	2.71

The importance of such findings will be used in the implementation of the thinking skills package and this will be shown at the end of this chapter. Rather than placing too much importance on the rank order, it is better to state that the low values in the table suggest that all of the statements do have a significant part to play in this package. It is not possible for me to state with great certainty the external validity of such a study since these results have only been obtained within my institution. However, on a qualitative basis my findings do agree with Raw's findings in that these eleven areas are important and do need to be addressed. The sample size used in my study was N=96 (18 at A/AS level; 78 at GCSE).

Tackling difficult concepts via Mestre's ideas.

Being such an important area of the thinking skills approach, it was important to search for other research in this field that could add further validity to the work of Raw. Similar work has also been conducted by Mestre (2001). Mestre draws upon research carried out by Chi (1981) and the US National Research Council (1999) that has summarised the past 25 years' work in this field. Mestre makes the following statements based on this extensive research:

1. Experts can access their knowledge quickly and efficiently. Experts retrieve knowledge that is relevant, spending less time on searching for the necessary systems needed in memory to solve problems.
2. Experts tend to apply 'major principles' to problem solving whereas novices will look at the more superficial aspects of a problem. In particular, expert learners

tend to apply their understanding of laws such as conservation of energy or momentum to problems rather than jump immediately to problems that involve the blind use of equations that are not totally understood.

3. Problems occur when students build new knowledge on existing knowledge. This constructivist nature of knowledge suggests that when new knowledge conflicts with existing knowledge, the new knowledge is not accommodated in ways that are useful for long-term recall or for use in problem-solving tasks (Anderson, 1987; Schauble, 1990; Resnick, 1983; Glasersfeld, 1989,1992).
4. A teacher's expertise in a discipline, such as physics, is an essential but not sufficient condition for effective teaching (Mestre, 2001). In many cases, the teaching strategy needs to be matched to the learning style.
5. Assessment types need to be scrutinized properly. Summative assessment is not sufficient as an assessment style as it does not give feedback to all those involved. Formative assessment is necessary as a feedback tool and it needs to be explicit.
6. Transfer of knowledge flexibly across different contexts (Mestre, 2001) is a fundamental goal yet very difficult to achieve. This is seen in physics when skills learned in maths cannot be applied successfully in physics classes. Specific strategies (which Mestre calls 'concept scenarios') are useful when teaching students to apply fundamental laws to their own 'new' situations. In this way, students can design situations in which laws such as the conservation of momentum and energy can be used in situations that are more 'sophisticated' or just 'less constrained and predictable' than a bouncing ball or a pendulum.

7. Mestre reinforces the importance of ‘metacognition’ (Brown 1975, Flavell, 1973) and its role in the improvement of ‘transfer’. Metacognition refers to strategies that allow learners to become more aware of themselves as learners and it includes the ability to regulate, plan and monitor success (Mestre, 2001, Schraw, 1997).

Mestre states:

“...Promoting the habit of reflecting on one’s own learning is also pivotal in physics courses that deviate from the norm in pedagogy...in cases...instructors should communicate with students why the course is being taught the way it is, and explain how research on learning suggests that the approach being used is superior to the teach-by-telling method.”

Mestre’s work has caused him to formulate the following suggestions, based on a thinking skills approach and based on his research and the research of other prominent figures:

1. Physics content and pedagogy should be integrated
 - a. The content of a physics course needs to be linked to ideas on cognition, thinking and learning.
 - b. Although teachers can facilitate knowledge, students must learn the work themselves.

2. The teaching of content should be a central focus
 - a. The emphasis of a topic should be on understanding, in depth, a few major topics rather than a memorisation of facts on many topics.
3. Ample opportunities should be available for learning the ‘doing of science’
 - a. Science requires lots of content knowledge as well as lots of processes involved in doing investigation work – knowledge of the process of science.
4. Ample opportunities should be provided for students to apply their knowledge flexibly across multiple contexts.
 - a. Research shows that knowledge gained in one context can seldom be applied to situations in related contexts. These contexts *initially* look as though they are unconnected, but they are linked by ‘major’ ideas such as laws.
5. Helping students organise content knowledge according to some hierarchy should be a priority.
 - a. Recall and application of knowledge requires a highly organised mental framework. Major facts need to be at the top of the hierarchy with less important or ‘ancillary’ facts placed lower down.

6. Qualitative reasoning based on physics concepts should be encouraged.

- a. Tacit knowledge needs to be made explicit to help students recognise it, learn it and apply it. This can be done by constructing qualitative arguments using the physics being learned. By constructing and evaluating arguments, students can begin to appreciate the role of conceptual knowledge in ‘doing science’ (Mestre, 2001).

7. Metacognitive strategies should be taught to students.

- a. Pupils should be asking themselves questions about their current state of learning. Self-reflection can allow them to learn more efficiently.

8. Formative assessment should be used frequently.

- a. Assessment is needed to provide feedback to students and to teachers to guide learning and teaching. Formative assessment allows students to learn what they don’t understand and it allows teachers to tailor their instructional strategies to help students achieve the appropriate understanding.

Mestre’s work condenses much that has been written on the area of thinking skills in the past 25 years.

Tackling difficult concepts via Georghiades' work.

Georghiades (2000) augments Mestre's work in his paper 'Beyond conceptual change learning in science education: focusing on transfer, durability and metacognition'. Georghiades uses previous research (Driver, 1989) to build on the notion that the learner constructs knowledge in a personal and social context. Like Mestre, Georghiades states that new knowledge and understanding are built on previous experience. Conceptual change learning, as Georghiades refers to it, bases its structure on a number of implications that have been developed by researchers in the field (Driver, 1989, Nussbaum and Novick, 1981, Shayer and Adey, 1989). To summarise, these implications are that learners need to be responsible for their learning, that they need to change their conceptions, that knowledge is personally and socially constructed, that teaching is not merely 'transmission' of knowledge, but the negotiation of meaning and that science and curriculum are not just facts, but resources to allow students to reconstruct understanding of their environment. (Driver, 1989)

When delivering a CCL curriculum, the sequence needs to have some 'special' structure that sets it apart from non-thinking skills structures. Such a structure is stated below:

1. The teacher makes children's alternative frameworks explicit to them
2. The teacher presents new evidence that does not fit and so induces dissatisfaction
3. The teacher presents the new framework and explains how it can account for the previous anomaly. (Nussbaum and Novick, 1981).

The idea of 'cognitive conflict' where the student is given a new piece of evidence to 'confuse' them is a fundamental part of thinking skills curricula and will play a major part in the implementation stage. Similar ideas have been suggested by Strike and Posner (1985), Adey and Shayer (1989), Scott, Asoko and Driver (1991) and Watts and Alsop (1997).

Georghiades further states the importance of 'transfer', 'durability' and 'metacognition'. Since transfer and metacognition have already been discussed, it leaves only the role of durability to be discussed.

Durability refers to how 'durable', 'long-lasting' or 'permanent' learned scientific conceptions are. Conceptual change learning must assume that there is a conception held by a student about a certain topic. If this conception is called 'conception A' then a CCL strategy will try to establish a new improved 'conception B' via an appropriate CCL interaction. If now a new conception, conception C, is expected to be constructed so as to replace or help in the subsequent evolution of conception B then two possibilities, as argued by Georghiades, may occur. Firstly, this evolution may be successful and lead to a new improved model known as conception C; this is the desired result. Alternatively, conception B might not have been firmly established and a regression or conceptual decay might take place back to conception A. This may occur because the material learned has been learned and forgotten in a short time, leading to a lack of durability. Georghiades defines 'durability of conceptions' as:

" ...I define durability as that which answers the question: 'How long does a conception remain in effect, within the learner's repertoire?'" (Georghiades, 2000).

Durability is a time-dependent quantity in many cases. In order to develop a high understanding of an area of physics it will be necessary to spend many hours practising strategies that reinforce the fundamentals of new conceptions. As far back as 1922 Thorndike associated success in mathematics with 'drill', the repetition of numerous problems until answers were correct. Despite being criticised for its lack of breadth, Thorndike's methods are still used today in maths classes where students need to practise maths questions in order to become familiar with the methods necessary for their solution. The main criticisms here would be that drill does not encourage transfer, neither does it necessarily provide 'understanding' of the mathematics principles involved. However, in its defence, a series of correct answers will increase durability since, as Georghiades has stated, the drill has provided a conception that will remain in effect within the user's repertoire of skills.

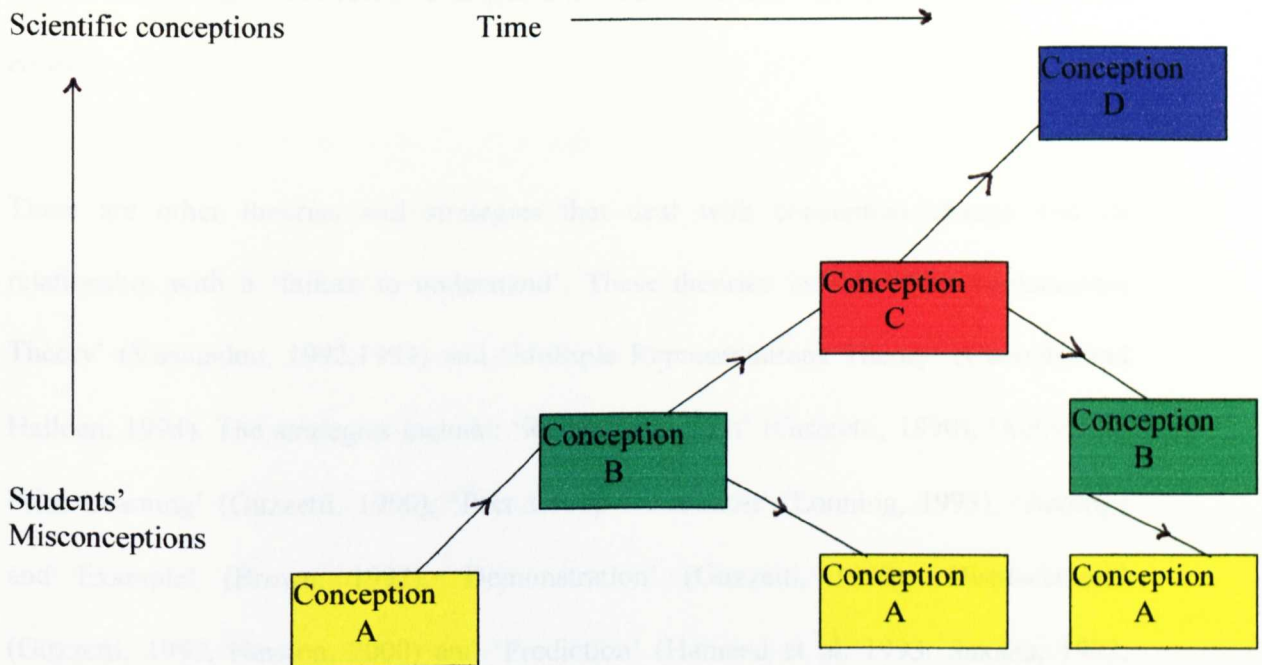
Durability is enhanced by practice, but, more importantly, by deliberate practice which is usually solitary (Butterworth, 1999). The 'ten year rule' (Ericsson, Krampe, Tesch-Romer, 1993) is a rule that applies to highly competent performers in the fields of science, mathematics, swimming, chess and musical composition. In the findings of this US-German team of psychologists it appeared that very intense, repetitive, deliberate and solitary practice is mostly responsible for better performance. They found that top professional musicians practised for 24 hours per week compared with only 9 hours for

those who were destined to teach music. The same was true when chess players such as Judit Polgar and Bobby Fischer were investigated as well as a mathematician, Wim Klein, who had laboriously learned how to calculate the 13th root of a 100 digit number in less than 2 minutes.

The simple lesson to be learned from this is that durability and subsequent expertise requires practice and hard work! Prodigies may have a gift, but that gift will not be realised without enormously high subsequent effort.

Problems occur with durability when the held conception is 'embedded' (Georghiades) deeply in the holder's mind (referred to as consistency). A highly consistent misconception will be more difficult to 'uproot' than a misconception that is used inconsistently. Georghiades argues that durability and transfer can be improved by using metacognitive instruction. A simple model showing what can happen during a conceptual change intervention is shown over the page:

Fig 5.2: The development of scientific conceptions with time.



As the diagram shows, moving from left to right on the horizontal time axis, new conceptions can be formed that remain stable or the new conceptions may become unstable causing a decay back into the previously held conception.

Despite being a useful model of conceptual change, Georgiades' model is only one view of conceptual development. Some argue (Newton, 2000) that these concepts, the new and the old, remain in 'parallel'. As Newton states in his book 'Teaching for Understanding':

"I suggest that,..., some strategy is needed in the event of misconceptions that resist change strongly and tend to co-exist with the desired conception. It may not be clear which conceptions are susceptible to replacement and which are not. A strategy which

begins with and extends a replacement approach is, therefore, likely to be economical since it may change what can be changed and lead into a treatment for the more difficult cases."

There are other theories and strategies that deal with conceptual change and its relationship with a 'failure to understand'. These theories include 'The Replacement Theory' (Vosniadou, 1992,1994) and 'Multiple Representations Theory' (Caravito and Hallden, 1994). The strategies include: 'Refutational Text' (Guzzetti, 1990), 'Activating Prior Learning' (Guzzetti, 1990), 'Peer Group Discussion' (Lonning, 1993), 'Analogy and Example' (Brown, 1992), 'Demonstration' (Guzzetti, 1990), 'Displacement' (Guzzetti, 1993, Newton, 2000) and 'Prediction' (Hameed et al. 1993, Saxana, 1992, Newton, 2000). Rather than expose all of these aforementioned theories and strategies in detail here, a summary is provided of their most important characteristics in appendix 27.

As much of the research mentions metacognition as an engine for delivering thinking skills and for allowing students access from concrete to formal operational thinking then it will play a major role in the implementation structure that is shown at the end of the chapter.

Multiple Intelligences:

Multiple intelligences is the work of Howard Gardner an American educationalist. Gardner's main belief was that IQ tests used in schools were inaccurate because they were only testing two main types of intelligence, namely linguistic and mathematical intelligences. Gardner's theory is that there are at least eight types of intelligence that are present in the mind and used by students in different amounts at different times. The eight intelligences that he proposed are:

Musical, kinaesthetic, mathematical, linguistic, inter-personal, intra-personal, spatial and naturalistic. Gardner also suggests that a spiritual or existential intelligence may also exist. Gardner's theory is enhanced by previous work carried out by Handy (1994) who states that there are 9 intelligences, similar in structure to those proposed by Gardner.

As stated by Anna Craft in Teaching Thinking (2001):

"...Gardner's is a theory of individual difference. He suggests that whilst we all have a wide range of intelligences, we each have them in varying strengths. The mix comes from birth, values, training and motivation. He suggests we can either ignore that, as the educational system tends to – or we can exploit it."

Gardner's criteria for accepting this model of multiple intelligences is based on the following criteria:

- i. That these intelligences can survive brain damage

- ii. Identifiable core operations
- iii. Support from psychological tasks
- iv. Support from psychometric findings.

There are also those who dispute Gardner's ideas of multiple intelligences. Arguments have been made with reference to Gardner's lack of rigidity when employing criteria. Gardner has explained away his choices by saying that he has made "An artistic judgement" which offers little justification to his choices. There are other problems associated with ideas such as symbolic encoding within and across domains, cultural aspects of intelligence and a lack of 'hard' evidence. Multiple intelligences may be a useful tool in many respects but it is not and never will be a set of physical laws.

Where implementation is concerned, multiple intelligences theory will not play a major part in terms of the overall structure. Multiple intelligences theory will be briefly explained to those students who are being used in the experimental group but there will be no major strategies used to try and identify whether multiple intelligences theory plays a significant part in this area of research. However, having said this, Gardner's theory will be used to accept that logical-mathematical and linguistic intelligences will be prominent areas in the learning of difficult topics in physics although the controversial 'domain specificity' of intelligences amongst learners will not be entirely accepted. In my opinion, intelligences do not exist within discrete boxes in the mind as unconnected systems. Instead, I believe the brain and mind to be something that is far too complex to even contemplate trying to involve in this study and so a detailed study of brain structure and

function can play no major part in this research. Multiple intelligences theory will be regarded as a possible structure in this research and it will be 'accepted' that certain approaches to problems may be different depending on the 'favourite' or preferred intelligence of the learner.

As part of my preliminary research, students who made the transition from GCSE to AS level in my school (N=30) during the last year were given a 'Thinking Skills Day' taught by myself on their first day back in September. The day itself involved a number of thinking skills strategies that were provided by the University of Newcastle from their course 'Improving Pupil Performance'. One such aspect of the 'Thinking Skills Day' was the determination of each of the students' multiple intelligence make-up using a pre-prepared questionnaire and multiple intelligences 'wheel'. Preliminary results showed that about half of the students agreed with the results that they obtained, but all of the students believed that multiple intelligences theory would have little effect on their learning and that the findings would have little or no relevance in an AS course.

In terms of the implementation, an appreciation of multiple intelligences theory will mean that logical, linguistic and visual or pictorial solutions will be made available to students when the learning episode is discussed at the end of each stage of the implementation work.

Mathematics:

Mathematics plays a fundamental part in physics and therefore the education of physics; it is a necessary tool. Much has been written about mathematics and the nature of symbolic knowledge in chapter 4.

In terms of implementation, the following difficulties associated with mathematics must be considered:

1. Most pupils can handle simple mathematical tasks although only a small proportion can apply mathematical modelling to more formal operational problems that involve bi-variate analysis.
2. Mathematics is highly symbolic which requires the teacher to realise that some students might be left 'stranded' at the macro corner during tuition.
3. Mathematical ability resides in the left parietal lobe of the brain.
4. Mathematics needs practice.
5. Mathematics suffers from problems involving transfer and durability.
6. Mathematics is considered boring by many students and this might be due to the way in which it is taught, over-practised or learned. One aspect might be a mismatch between multiple intelligences, requiring more strategies.

Apart from the statement about mathematical ability residing in the left parietal lobe area of the brain, the other issues can be addressed and implemented via a thinking skills package. To solve problems involving transfer and durability then strategies can be employed that involve practice, metacognition and cognitive conflict. To stop mathematics being boring then stories, mnemonics and humour can be involved. Mathematics from textbooks, blackboards and dictation does not inspire pupils and it does not persuade students that they should think further about it after the bell has gone for the end of the lesson and hence transfer between subjects will effectively stop at this point. Mathematics, like all learning, must have a key fun element.

Other useful methods for augmenting memory, transfer and durability is the use of mnemonics in lessons as well as other techniques such as formula triangles that require less chunking. Mathematics can be delivered in such a way to increase the students' desire to listen and learn and to attempt difficult algebraic functions such as transposition.

Other peripheral mathematics tasks such as using the correct number of significant figures in the final answer and remembering to use the correct units in the final answer also need to be addressed. One way of doing this, via a metacognitive method, is by getting students to become familiar with examination expectations via analysis of the mark schemes and by encouraging students to write their own exam questions as though they were setting questions to myself, other students or for analysis by a chief examiner. Giving students access to the way in which the examination system is run would allow them to see that these papers are only set by similar human beings, which would help

reduce the 'fear' of examinations. Explaining that the exam is written so that very few people achieve top marks and that the mark scheme is designed to test and reward what you do know, not penalise you for what you do not know could reduce fear of examinations. It will always be the case that some students enjoy mathematics and that some students do not enjoy mathematics, but a fun approach, in my opinion, is the only way to remedy the problem. Preliminary research findings showed that for my GCSE physics students there was a correlation of 0.535 ($p\text{-value} = 0.001$) between how well the students performed in an arbitrary 'maths for physics' paper, designed for their physics GCSE course and their average physics score in three recent 75 multiple choice question tests relating to the areas of Earth and Space, Forces and Energy, respectively. This shows that there is a high positive correlation between exam performance in physics and mathematical ability.

Language:

As a science subject, language would not be the first area that physics students would necessarily state as being the most difficult aspect or the most obvious cause for concern. However, preliminary research conducted by myself and a review of some of the literature in this field indicated that major problems did arise in certain areas. The preliminary research and literature review highlighted the following areas of concern and it is these that will be included in the implementation stage of the thinking skills package:

1. Language is a pre-requisite for abstract thought (Bransford, 1999) and so there should be a link between the depth of language skills held by a student and the extent to which abstract thought can be executed.
2. Students misinterpret words in physics and use them out of context. This might be because there are ambiguous cases within the subject.
3. The vocabulary and nomenclature of physics is highly specialised and a single word in physics, such as momentum, moment, fission, fusion, etc., is merely a label for a great deal of underlying physical, mathematical and further linguistic knowledge. If not fully comprehended, the structure of learning and subsequent understanding will be severely damaged.
4. The origins of certain words such as latent, satellite, horsepower, electron could help children with the understanding of words within the confines of the topic. (Sutton, 1992)
5. As well as linguistic problems relating to phenomena that are seen as physics terms, there are also many difficulties relating to the language of the scientific method. In particular, words such as hypothesising, analysing, evaluating, anomalous, validity and reliability are poorly understood because the students do not associate these 'unfamiliar' words with the mechanics of the processes involved in each case. The words are also often new to them at GCSE level.

As part of the preliminary research, to obtain a measure of how useful a strategy might be to identify language as a main factor in learning I administered some tests. The first three tests were multiple choice tests examining how well the physics content had been learned

by my experimental year 11 class in their Earth and Space, Forces and Energy topics, respectively. I obtained a correlation between their average test score and their vocabulary score of 0.605 ($p\text{-value} = 0.001$). The vocabulary score was determined by asking them to identify correct meanings from 25 multiple-choice questions and by asking them to explain the meanings of 40 other words along with ambiguous meanings that might arise in everyday usage. Despite not expecting such a strong correlation, the values indicate that language plays an important part in the acquisition and understanding of physics knowledge and so it will be used in the implementation.

Other factors concerning language development pertaining to brain structure, synaptic selection, accommodation and elimination as well as the role of family conversation to language acquisition have been excluded from my study since they are not relevant at classroom level.

Confidence and metacognitive self-regulation.

When I first started the preliminary research, the idea that students' confidence could play such an important part in the understanding of difficult concepts in physics was not believed to be particularly important. After subsequent research, a review of the relevant literature and informal interviews with students, it became apparent that a confidence-based metacognitive approach could have a positive effect on students' learning and understanding. Subsequent work with my students has shown that the quite tacit area of confidence has proved to be very important where successful learning is involved.

Work by Hasan, Bagayoko and Kelley (1999) has indicated that using a Lickert-style certainty of response index (CRI) can be used in multiple-choice tests to determine whether misconceptions are present in students' understanding. The work carried out by Hasan, Bagayoko and Kelley, in the field of classical mechanics, provided three main findings, namely:

- a) CRI style tests can be used by teachers and students to help differentiate misconceptions from a lack of knowledge;
- b) CRI values can be used to modify instructional deliveries accordingly with the intent of removing these misconceptions.
- c) CRI can be used to assess progress or teaching effectiveness when pre-tests and post-tests are administered.

How do the areas discussed in this chapter allow difficult concepts to be tackled via a 'Thinking Skills' approach?

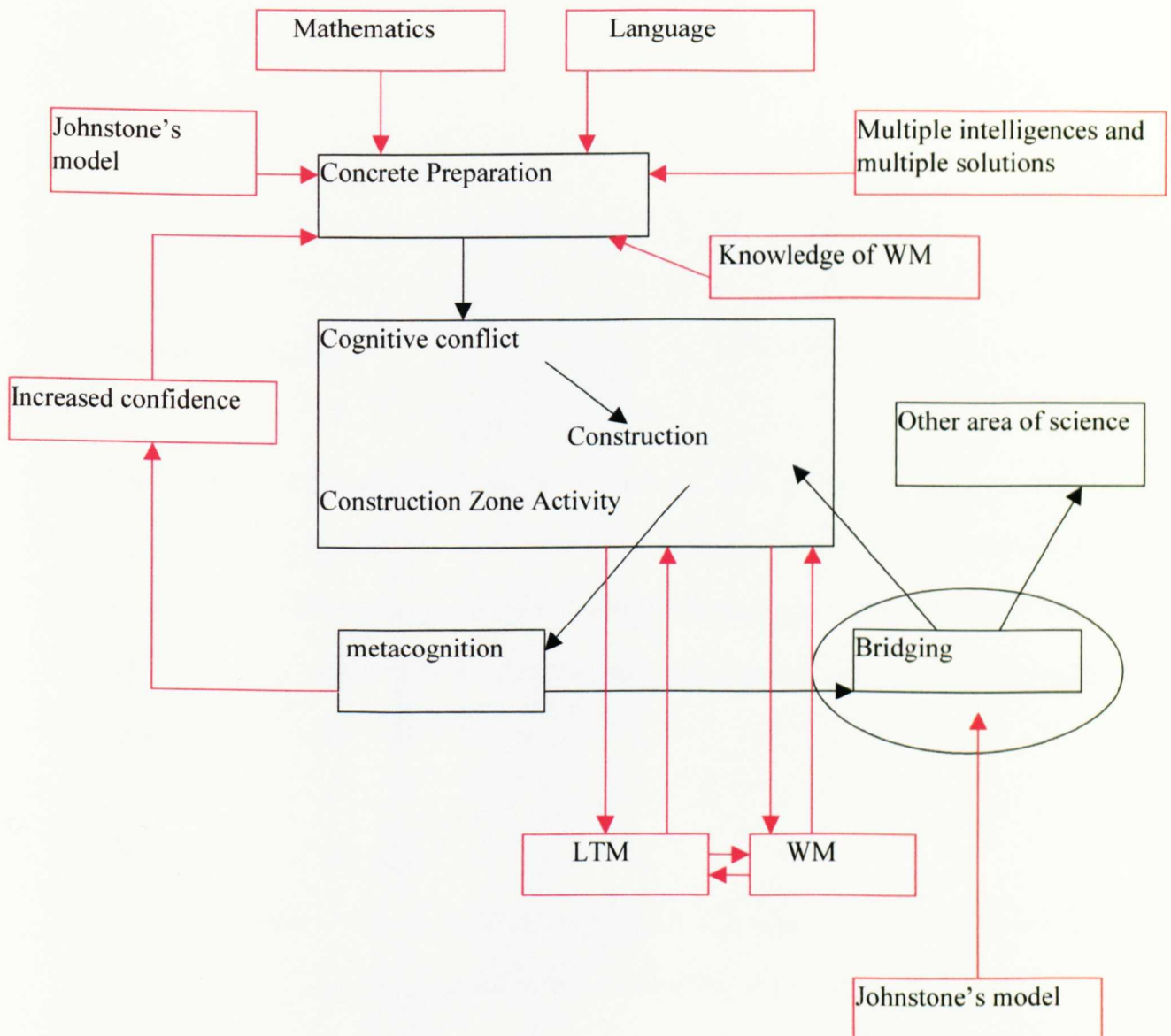
An appreciation of the areas that cause physics material to be seen as difficult is important because it allows the teachers and students to concentrate on these areas when the teaching and learning occurs. It is important to see how these areas might play a part in a 'thinking skills' programme. In figure 5.3, a possible structure is highlighted to include the areas discussed. The areas in black are those that have been taken from Shayer And Adey's CASE programme. This programme is Piagetian in structure, showing the four main areas of concrete preparation, cognitive conflict, metacognition and bridging. The areas in red are those areas that are not included in the CASE programme, but have

been found to be important from my research. These areas have been added to the CASE programme to strengthen the design of the thinking skills programme, since the CASE programme does not take these areas into account.

In figure 5.3, WM and LTM refer to working memory and long-term memory respectively. The concrete preparation stage accesses information from the areas mentioned in this research and uses these as input for the construction zone where cognitive conflict is allowed to occur. Heightened understanding and subsequent metacognition allows confidence to increase and this new level of understanding can be used for future preparation.

This process is driven by the working memory which relies on the long-term memory for prior knowledge. Successful learning will also lead to bridging where new conceptions can be linked to other areas of science or fed back into the construction zone so that further conflict can happen.

Figure 5.3: Thinking Skills design, showing how CASE and non-CASE materials can be used in conjunction to deliver a thinking skills-based programme.



Chapter Six

Implementation of Thinking Skills Approaches in the Classroom

In this chapter the thinking skills taxonomy that was employed will be explained. The programme was implemented in three stages, taking a total time of 7 weeks. The three stages were:

1. The diagnostic stage
2. The main teaching stage
3. The results acquisition and analysis stage

The diagnostic stage:

This stage involved the collection of preliminary data before the thinking skills programme (the treatment) was constructed and delivered to any students. The purpose of this stage to use the data as a comparison with the final data to determine whether any major changes had taken place. Much of the diagnostic stage had already been conducted as part of the preliminary research work.

The diagnostic data contained:

1. Information based on students' current states in terms of concrete or formal operational thinking (from 2A to 3B based on Shayer and Adey)
2. Information relating to students' mathematical abilities.
3. Information relating to Johnstone's model of macro/micro/symbolic knowledge

4. Information relating to preferred learning styles based on Gardner's theory of multiple intelligences.
5. Information relating to working memory and the chunking of information.
6. Information relating to the understanding and learning of language in the context of physics content and physics process.
7. Information relating to confidence and metacognitive self-regulation.

Much of this information lends itself to simple quantitative and qualitative analysis and this will be discussed more thoroughly in the results chapter.

The main teaching stage:

This was the most important stage. Preliminary and diagnostic information work helped to determine this. The structure of this will be shown on the next few pages and the reasons for this structure will also be explained.

The main teaching period lasted for 7 weeks and involved 14 separate teaching episodes. Week 1 involved 2 teaching episodes that focused on the nature of the research, its purpose and the theory underpinning it, but in such a way that the students did not realise that a research programme was being conducted (i.e. 'single blind'). Weeks 2-6 involved the main thinking skills teaching programme that used the main GCSE and AS level syllabuses as its content interwoven with the thinking skills programme. The control

Table 6.1: Thinking Skills lessons programme for GCSE Groups.

Teaching Episode	Title of Lesson	Physics Content	Thinking Skills Strategies Used
#1	Simple Electrical Circuits (theory) Simple Electrical Circuits (practical)	-Parts of a circuit. -Basic symbols. -Voltage. -Charge. -Current. -Energy. -Resistance.	-VAKi -Key words -KWL -Pole Bridging -CRI test
#2	Ohm's Law (theory) Ohm's Law (practical)	-Review of previous nomenclature. -Definition of Ohm's Law. -Structure of a resistor. -Equation for Ohm's law $R = V/I$.	-Key words -VAKi -Pole Bridging -CRI test -Wrestling Maths
#3	Series and Parallel Circuits (theory) Series and Parallel Circuits (demo)	-Structure of series and parallel circuits. -Conditions for current in each. -Conditions for voltage in each. -Conditions for energy usage in both. -Series and Parallel resistors.	-Key words -KWL -VAKi -Cognitive Conflict -CRI test -PMI
#4	I-V characteristics for resistor, diode and filament lamp.	-Ammeter arrangement. -Voltmeter arrangement. -Graphing (demo). -Practical determination of results for bulb and diode. -Graphing results.	-Key words -Pole Bridging -Cognitive Conflict -CRI test
#5	Electrolysis	-Nature of conduction in metals. -Investigation of electrolysis using covalent liquids and electrovalent	-Key words -Pole Bridging -Cognitive Conflict -KWL -CRI test

		solutions.	
#6	The Resistance Investigation.	<ul style="list-style-type: none"> -Plan investigation to show how resistance is dependent on variables such as length, material or thickness of a metal wire. -Make a prediction. -Design fair test. -Obtain data. -Analyse results. -Evaluate. 	<ul style="list-style-type: none"> -Key words -KWL -Metacognition Bubble sheets -CRI test -Cognitive Conflict
#7	Plenary Session	<ul style="list-style-type: none"> -Class Discussion -Sharing of Ideas -Ask the teacher -‘Phone a Friend’ 	<ul style="list-style-type: none"> -PMI -KWL -Metacognition Bubble sheets -CRI test -Concept mapping

Table 6.2: Thinking Skills lessons for Year 12 AS level Group.

Teaching Episode	Lesson Title	Physics Content	Thinking Skills Strategies Used
#1	<ul style="list-style-type: none"> - The Structure of the Atom. - The Nature of Particles. - Particle Interactions. 	<ul style="list-style-type: none"> - Atomic Structure. - Plum pudding model. - Rutherford's model of the atom. - Hadrons, Leptons and gauge bosons. - Strong, Weak, electromagnetic and gravitational forces. 	<ul style="list-style-type: none"> - KWL - Key words - Concept mapping - Ask The Teacher - 'Question Time' - Metacognition bubble sheets. - 'Wrestling maths' - CRI test
#2	<ul style="list-style-type: none"> - Quarks. - Antiquarks. - Photon model of EM radiation. - Pair production. - Annihilation. - Feynman diagrams 	<ul style="list-style-type: none"> - Quark structure of non fundamental particles. - Energy mass equivalence. - $E = hf$. - Feynman diagrams. 	<ul style="list-style-type: none"> - KWL - Key Words - Concept mapping - Ask the Teacher - 'Question Time' - Metacognition bubble sheets - CRI test - 'Wrestling maths'
#3	<ul style="list-style-type: none"> - Conservation rules for particle interactions. - Examples of interactions that can or cannot occur. - Gauge bosons. 	<ul style="list-style-type: none"> - Lepton number, strangeness, baryon number and charge. - Examples of violation of above. - Beta decay, neutron-neutrino interactions, positron decay etc. - Different gauge bosons involved in particle interactions. 	<ul style="list-style-type: none"> - Key Words - Concept mapping - Ask the Teacher - 'Question Time' - Metacognition bubble sheets - CRI test
#4	<ul style="list-style-type: none"> - Wave particle 	<ul style="list-style-type: none"> - Explanation of 	<ul style="list-style-type: none"> - Key Words

	duality. - Photoelectric effect.	how waves are particles and vice versa - Background history of de Broglie's work - Photoelectric effect. - Photoelectric equation. - The facts of photoelectric emission.	- Concept mapping - Ask the Teacher - Metacognition bubble sheets - CRI test - 'Raw Maths'
#5	- Line spectra. - The electronvolt.	- Why hydrogen has a line spectra. - Atomic fingerprinting. - Definition of the electronvolt. - Calculations involving eV and Joules.	- 'Raw Maths'. - Metacognition bubble sheets. - Key words - Concept mapping - CRI test
#6	- Refraction. - Total Internal Reflection.	- Refraction of light. - Snell's law. - Refractive indices. - Critical angle. - Total Internal Reflection. - Optical Fibres - Graded and Step Indexed fibres. - Uses of TIR	- Key words - Concept mapping. - CRI test. - Metacognition bubble sheets. - Pole Bridging.
#7	- Experiment circus. - Testing. - Revision. - Exam technique.	- Practical circus. - CRI testing. - Exam questions. - Revision structure. - Question Structure. - Raw's model.	- Pole Bridging. - Key words. - Concept mapping. - CRI test.

groups were taught the same content but without the application of thinking skills programme. The teaching structure that was used is shown on the previous four pages.

The third column in the teaching structure refers to the statutory work that needed to be delivered as part of the GCSE syllabus. The fourth column contains the thinking skills strategies that were used in each of the teaching and learning episodes. A summary of what each strategy does is tabulated below:

Table 6.3: Thinking skills strategies and associated background theory.

Thinking Skills Strategy	Area of Thinking Skills Covered
VAKi	Multiple Intelligences, Johnstone's Model
Key Words	Chunking, Language
KWL	Metacognition
PMI	Metacognition
Pole Bridging	Metacognition
CRI	Metacognition / Confidence
Wrestling Maths	Visualising Symbolic Knowledge
Cognitive Conflict	Cognitive Conflict, Transfer and Durability
Metacognition Bubble Sheets	Metacognition
Concept Mapping	Chunking, Metacognition, Durability
Ask the Teacher	Teamwork, Metacognition, Transfer
Phone A Friend	Confidence, Durability

More information is now provided about each of the twelve techniques listed in the table above.

1. **VAKi:** VAKi stands for 'visual auditory kinaesthetic' (West, 1997). According to this theory, knowledge is learned best if it is seen, heard and then acted out. When studying circuits, students can see and hear the effects of circuits, but these effects are often based on the sub-micro happenings in the circuit at atomic level. By allowing students to 'be' such things as charge, potential difference, current and resistance in a playful context, the sub-micro ideas become more macroscopic. In the first lesson, students are invited to be characters such as 'Miss Charge', 'Mr. Potential Difference', 'Mr. Resistance', etc. The energy, represented by chocolate, is carried around and fed to electrical components such as 'Mr. Light bulb' who converts it from electrical to light and heat energy. By doing this, the physics becomes more tangible and the interrelationships between abstract concepts such as energy, charge and voltage can be explained in a user friendly way. The control group was not given access to this approach at this stage and, instead, were taught the ideas mathematically via $Q = It$, $E = QV$ and through standard methods including circuit diagrams and exam questions.
2. **Key Words:** Key words allow students to focus in on the fundamental language of physics without overloading their working and long-term memory. During the initial teaching period, pupils had been told certain truths concerning science vocabulary and how it relates to examination performance. The two key statements taught were: no marks are awarded for 'the', 'if', 'and', 'because',

'then' etc. on examinations. The marks are only awarded for key scientific words such as 'current', 'potential difference', 'electromagnetic induction', 'diffraction', 'longitudinal', 'transverse' etc. The other statement was: 'The questions change, but the answers remain the same'. This idea exploits the problem caused, especially in physics, when students meet unfamiliar questions on exam papers. The superficial nature of the question is different, but the physics learned in class still applies between very slightly dissimilar contexts. The aim here was for students to concentrate on the key terms, their meanings and definitions and to realise that these will be the 'currency' on the written exam. Key words can be used in conjunction with concept maps once enough of them have been understood.

3. **KWL**: KWL is a strategy that stands for 'Know, Want to know, Learned'. At the start of a lesson, students were asked to write down a number of items, between five and eight, facts that they knew about that topic and that were relevant to the lesson title. Upon discussion, the students then wrote down another set of statements that they would like to have learned about before the end of the lesson. After these first two stages, the process of new learning began and students filled in the 'learned' column with their new knowledge at a later time, as it appeared. KWL strategies assist metacognition by allowing students to reflect upon their learning over a short period of time. The control group was not asked to use KWL.
4. **PMI**: PMI stands for 'plus, minus, interesting'. Students were given, or could independently generate, their own statements. The statement was then used to

produce a plus point, minus point and interesting point. As an example, students could be asked to perform a PMI exercise on a statement such as 'electricity should be a luminous green colour'. The possible answers could be 'a plus point of electricity being luminous green is that we could be warned when devices are live and so we could avoid being electrocuted. A minus point could be that luminous electricity could mean that we would be kept awake at night as we could not switch many appliances off. An interesting point would be that we could see how quickly electricity travelled when we switched appliances on.' Obviously, PMI answers will vary from student to student in both their content and the level of sophistication, which enables automatic differentiation and creativity of thought. It also enables the teacher to determine if any copying has occurred! The beauty of PMI is its efficiency. PMI can be quickly administered, it can be set by the teacher or it can be set as a homework where pupils are asked to 'do a PMI' for 3 or so statements of their own choice. In my own experience with younger students, the questions and answers that young children generate are far better than those that I could produce and this allows me as a teacher to engage in the learning process where the students have taught me something new. PMI is a highly metacognitive tool and it allows students to learn key facts needed in answers and to structure their responses. Since PMI only focuses on a small number of facts it allows key information to be learned efficiently without overwhelming the working memory. PMI was not used as a strategy with the control group.

5. **Pole Bridging:** Pole bridging is a technique used in practical situations in physics. Students talk themselves through their practical work in situ. For example, students performing a simple practical using simple circuits might say: ‘ I am putting a power pack in my circuit to provide a potential difference and I am connecting my wires, making sure that the circuit is complete and that the ammeter, switch, bulb and power pack are in series. Next I am placing a voltmeter in parallel across the bulb. I am now going to press the switch, oh dear, nothing has happened! Okay, Let’s have a look. Right it looks as though the filament has gone in this bulb, resulting in a short-circuit. I will replace it with another....ooh, it works.’ This would obviously continue throughout the investigative or practical task at hand. The advantage here is that the pupils are constantly reminding themselves of what they have done, whether it is correct, whether it needs fixing, whether it conflicts with currently held concepts and the teacher can hear their thinking also, which allows intervention to occur when problems are heard. Pole-bridging allows metacognition to be verbalised and, because it involves many areas of the brain (Jensen, 1995), pole bridging will appeal to more than one multiple intelligence so that more than a select few of the students will have access to the material. Pole bridging was not used in the control group.
6. **CRI:** CRI, or ‘Certainty of Response Index’ is a summative assessment tool. To enable students to help explain their difficulties and to help teachers identify possible areas that need extra revision, CRI values were given for answers to multiple choice questions. The scale used was a Lickert style scale where 1 represented a complete guess and complete lack of understanding whereas 5

represented total confidence in having understood the question and at having picked the correct answer. CRI is a metacognitive tool since it allows students to reflect on their thinking and their knowledge and it is intended that repeated testing within the learning episodes will allow the mean value of the CRI to increase because of reinforcement. CRI was used in each lesson to answer questions. Each lesson, the test was increased in size so that by the end of the stage, the test was covering all aspects of the course. CRI was not used with the control group.

7. **Wrestling Maths:** Wrestling maths is a thinking skills method invented by myself. Mathematics is a subject that many students can do well and many others cannot do well, but very few questioned stated that they 'enjoyed' maths, even those who were good at maths. To make this subject more 'interesting' I decided to find out what the students liked. To my surprise, it turned out that WWF wrestling was the skill that they enjoyed more than anything else. I do not like WWF wrestling, but I decided to use wrestling as a structure to get maths across in the classroom based on the idea that if the students can relate to it then they will do well. What is 'wrestling maths'? Basically, equations that occur in GCSE courses are of the form $A=BC$. In equations of the form $A=BC$ the term A is always 'top dog'. If B attacks A then B is wrestled to the ground, as is C if it attacks A. By showing this using VAKi and via the electronic whiteboard allows students to ascertain that $A=BC$, $A/B=C$ and $A/C=B$. This method is just a more student-friendly way of saying 'if it is times'd on one side then it divides when it goes across the equal sign', which does not appeal to students because it does not

involve wrestling, which students enjoy. Obviously, getting students to overcome the gimmick of wrestling maths is important, so reference to equations and to the 'wrestling' model needed to be reinforced with mathematical problems and 'formula triangles'.

8. **Cognitive Conflict:** Cognitive conflict is a central pillar of thinking skills packages. Cognitive conflict involves allowing students to develop a set of comfortable beliefs concerning the topic that they are studying before introducing a question or concept that does not 'fit' into this model. The most commonly used example is probably the example where students accept that 'light' objects float and 'heavy' objects sink before introducing the question 'okay, so why does a ship not sink?'. This leads to cognitive conflict and a new concept 'density' must be introduced. For an electricity topic, length and resistance are usually the variables that are studied and students are asked to explain what happens to electrical resistance as length increases, based on simple collision theory. Once this has been covered, students are then put into a period of cognitive conflict by having to explain why this is not true when the width of the wire increases. Cognitive conflict is the 'engine' for transfer from concrete to formal operational thought. Without cognitive conflict, thinking skills programmes would not exist as effective ways of 'moving' students from an ability to study single variable systems to an ability to compare the relative effects of bivariate systems. Cognitive conflict strategies were used for the control group but they were not delivered in the same manner.

9. **Metacognition Bubble Sheets:** These are resources that I have designed.

Students are provided with ‘bubble’ sheets resembling what ‘thoughts’ look like in cartoon strips. Whenever a student has a problem with a concept then they fill in a ‘bubble’ sheet that exposes their difficulty. This sheet is ‘posted’ to the teacher who then has to ‘write back’. This method, successful with younger students, induces metacognition and aids the thinking skills process. Other metacognitive sheets involve students being given a blank question grid with room to write a question with a diagram and then a space underneath that requires the student’s mark scheme. Again, this process induces metacognition and allows access to the mechanics of how questions might be structured and marked at GCSE or AS level. Metacognition bubble sheets were not used with the control group.

10. **Concept Mapping:** Concept mapping is a useful strategy introduced by Ausubel (1986) and continued by Buzan (2000) amongst others. Once information has been learned and the interrelations between that information ‘understood’ then the information can be pieced together in a concept map. The concept mapping strategy serves two purposes as it provides teachers with a diagnostic tool that allows them to see how well students have pieced together information and, if the concepts map together successfully, then the concept map can be used as a very efficient revision tool and an efficient means of ‘seeing’ how process and content link together on a single sheet of A4 or A3 paper. Since concept mapping has important implications for teaching and learning then it allows the student and the

teacher to redefine their understanding of the topic; the teacher can also learn from the student. Concept mapping was not used with the control group.

11. **Ask the Teacher:** Ask the teacher is a metacognitive tool where the student asks the teacher questions that have arisen during the learning episode. The student asks the questions to the teacher at the end of the teaching and learning episode. Ask the teacher is similar to the metacognitive bubbles idea where students ask the teacher questions and provide their own answers. This procedure was not used with the control group.
12. **'Phone a Friend':** This is a technique used to make the metacognitive process more verbalised and it allows transfer and durability to develop. The pupils can pretend to phone a friend during the 'ask the teacher' session and ask for advice on multiple choice questions posed by the teacher or by other students. Longer, more structured responses are also given for homework where friends can work together in consultation. Phone a friend tends to get the pupils more interested in their work than standard teacher lead question and answer sessions. The technique is useful for the teacher since it allows the teacher to see the thinking that is occurring for two students at once, hence doubling the amount of feedback per given time. The more shy students tend to enjoy this technique because the culpability of wrong answers is shared so they are not as embarrassed when they get the answer incorrect. The only problem posed is the use of mobile phones in the lesson by students. The school provides two mobile phones to avoid this problem! Phone a friend is a technique that was not used with the control group,

although mounting pressure did mean that they will be using the technique in future lessons that do not involve the research process.

As well as the techniques used above, the experimental group for the GCSE class had to keep a diary of the learning episodes. In each of the homework assignments, students were asked to write a few comments about how they thought they did in that lesson. The questions they had to answer were:

1. On a scale of 1 to 10, how much did I enjoy the lesson?
2. On a scale of 1 to 10, how much did I understand what we did in the lesson?
3. What did I learn today?
4. What did I find difficult today?
5. What could I do to improve my knowledge?

These responses were filled in every week and checked every fortnight by myself. The diary still remains an ongoing metacognitive technique that encourages self-assessment and reflection on the current state of learning. The diary was not meant to be 'too personal' and so no comments were allowed that put members of the class down since the classroom was declared a 'no putdown zone'. The diaries, referring to academic material only, were collected in at the end of the term once the work had been covered.

The year 12 scenario was different. There was only one year 12 group for the AS physics course and the syllabus has changed since 2000. This meant that I could not have a control group and an experimental group. However, I did have access to the Yellis results that my school possesses and I could compare these to the results that they obtained in their modular exams that they sat in the January and June sessions of that year. My year 12 students were also keen to provide me with feedback based on their opinions of the thinking skills processes used and how they affected their learning, revision and subsequent examination performance.

The year 12 modular arrangement did, however, make the administration of a thinking skills package very easy, since the whole of the first AS module was delivered via a thinking skills approach in one half term. The module is completed in October and then examined externally through the AQA the following January. The first module had been completed and the results have been sent to the school and received by the 14 students who took the modular exam, entitled 'particles, waves and quantum phenomena'. The techniques used in the year 12 thinking skills package were the same as those twelve strategies mentioned above, although certain subtle differences needed to be imposed. The structure of the year 12 thinking skills package along with comments is shown on the next page.

The physics content of the AS level course is significantly different to the GCSE course. In particular, the AS level module that will be used (particles, waves and quantum phenomena) is much more sub-micro, more difficult to visualise and has a higher

mathematical content and level of sophistication. This meant that there would need to be differences in the thinking skills strategies used at AS level. The AS level course meant that 'Raw Maths', the thinking skills programme recommended by Andy Raw (1999) was utilised. 'Raw Maths' uses the chunking and algorithmic ideas of Andy Raw to break problems up into their constituent parts which makes the problem easier to deal with, especially for those students with lower GCSE grades in maths and physics. 'Question Time' was a strategy used at AS level instead of the less adult 'phone a friend' technique used with GCSE students. In this new technique, students were briefed before the lesson that they were going to be questioned by a member of the class concerning a specific topic. The student being questioned was given a 'secret' topic that he or she was going to be asked about such as 'total internal reflection'. Another anonymous member of the group was given a list of questions that he or she was going to quiz the other student about. For example, that student might be given the question: 'could you please explain the importance of the role played by the critical angle in the process of total internal reflection and explain how it is determined?'

The student who has volunteered to be questioned was put 'on the spot' and had to explain the answer. Lower ability students were given subtle clues by myself as to the nature of the question that they would be asked so that they were more confident. Higher ability students (those obtaining A and A* grades at GCSE) were given less help and asked to provide a set of questions that they thought they could be asked in order to aid metacognition.

Chapter Seven

Results

The results obtained during this research period can be split into two parts. Firstly, there were the preliminary results that were obtained prior to the implementation of the thinking skills programme at GCSE and AS level. The preliminary investigation work was referred to in chapter 2 and so it is only necessary for a brief summary of the quantitative results that were obtained from the preliminary investigation to be mentioned here. Secondly, there are the main results that were collected after the thinking skills programme had been implemented. These are the results that indicate how the students have progressed since the delivery of thinking skills programme.

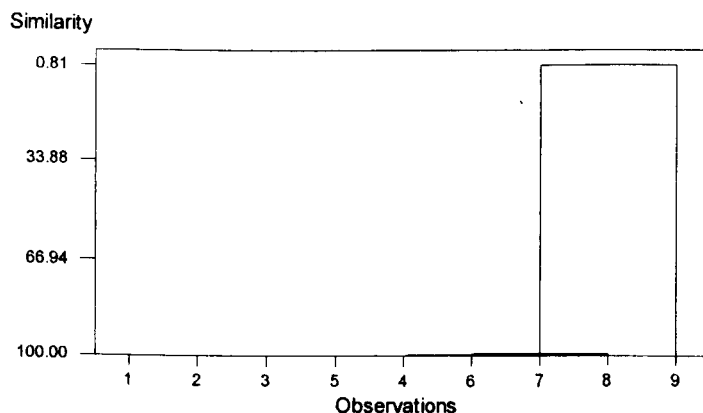
Preliminary Results:

As mentioned in chapter 2, it was found that some areas of the physics syllabus were deemed to be more difficult than others. These preliminary findings are adequately covered in that chapter. However, other preliminary findings that relate to working memory, mathematics, confidence in answering questions, Piagetian stages of cognitive development, multiple intelligences and the link between investigative work and classwork were also discussed. These preliminary findings will now be summarised before illustrating the main results.

Preliminary working memory data:

The preliminary working memory data was conducted to try and determine whether too much immediate information in too short a space of time caused overloading of the working memory. The results obtained showed that there was a dramatic drop from similarity between students' responses when the length of the number string reached 7 digits. More results were collected on working memory over the next two years. These have been included in the data that is shown in the dendrogram in figure 7.1, below.

Fig. 7.1 Dendrogram to illustrate preliminary and main working memory results.



As shown on the dendrogram above, the degree of similarity drops from nearly 100% similarity at 6,7 and 8 digit numbers to a very low similarity of 0.81% at 9 digits (N=189). This result suggests that there is a dramatic change in how much information can be successfully stored by the learner and that this change occurs somewhere between 6 and 9 digits. This result is actually data obtained from the main research period but the

same pattern was found in the preliminary section with a drop from 100% similarity at 4 digit length to 2.37% at 9 digits (N=60).

The significance of the findings concerning working memory is that there appears to be a close relationship between the size of the data per unit time and the reliability of it being immediately recalled and explained. The main results section will elaborate how this idea has been utilised in the main research episodes at GCSE and A level.

Certainty of response index (CRI) and metacognitive self-regulation.

An important 'pillar' of thinking skills strategies is the area of metacognition. The most appropriate and efficient way of collecting preliminary information concerning metacognition was to ask students to grade their performance on multiple choice tests from 1 to 5, with 1 representing a complete guess and 5 representing complete confidence in their response. This research could provide insight into the metacognitive techniques applied by the more able and the less able learners. These self-regulatory results have been referred to as CRI or certainty of response indices. A student simply grades their answers in multiple choice tests based on how they feel they have done. This is used as a way to diagnose confidence in performance and to help students be more critical of what they do and do not know. These preliminary findings are shown overleaf.

Table 7.1 Results to show CRI responses for tests taken at GCSE and AS level.

Year Group	Topic or module	Correlation	p-value
Year 11 GCSE	Forces and Motion	0.465	0.004
Year 11 GCSE	Earth and Space	0.449	0.009
Year 12 A level	Mechanics/Electricity	0.503	0.001

The preliminary results show that there is a positive correlation between the score obtained on a test and the average value of the CRI (certainty of response index) for each student. To a large extent, the results show that the students who get the best marks know that they are answering the questions better than those students who get lower marks. This is an encouraging preliminary result because it means that if the low achievers realise that they are not so sure, then there is potential to increase their knowledge of the subject and their knowledge of themselves via the mechanism of metacognition. These results also allow metacognitive strategies to be designed with the intention of increasing confidence, knowledge and self-awareness. The preliminary result obtained gave me the confidence to construct lessons that allowed terms such as 'confidence' and 'metacognition' to be included as appropriate things that did have a real impact on learning. Previous to this discovery, how 'confident' a student was answering a question and how 'metacognitive' their learning style was came a definite second to the 'content'

of the material being taught by the teacher. The main outcome of the CRI and associated metacognitive strategies employed in the main research will be discussed in the main results section.

Mathematics

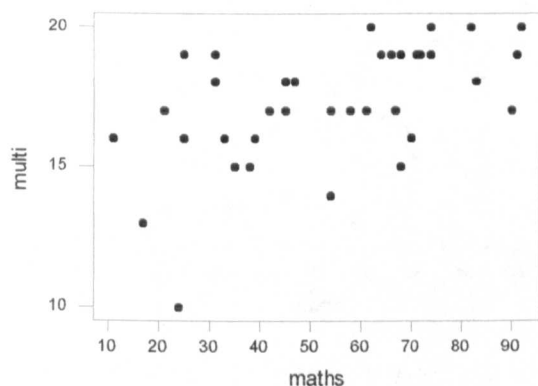
Preliminary research into mathematics showed that there was a correlation of 0.535 (p-value = 0.001) between how students performed in their mathematics exams during that year and how well they scored on their physics examinations in the same year. This was carried out only for GCSE students in the sample. The same result could not be obtained for the current year 12 AS physics group since many of them do not take AS level maths. However, the current year 12s' maths scores showed a correlation of 0.603 (p-value = 0.001) with their final mock physics result when analysed.

This preliminary result shows that there is a quite significant correlation between how well pupils do in maths and how well they do in physics. For the main results stage this finding will be used, but it will be incorporated into the more sophisticated model of macro/micro/symbolic knowledge at GCSE and the 'Raw Maths' technique used at AS level to help AS students deal with 'multiple layer' problems.

A graph showing the preliminary findings for a GCSE sample in my school is shown below. The correlation is 0.535. The vertical axis represents average performance in three

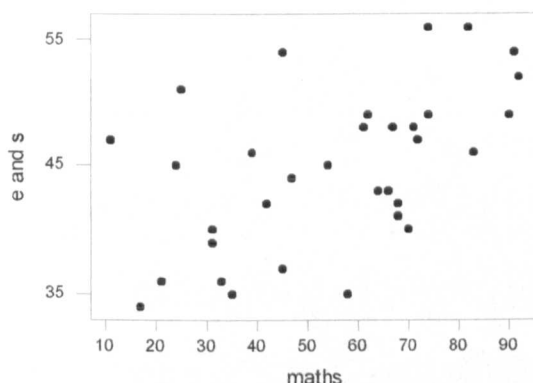
multiple choice exams over a period of six months and the horizontal axis represents exam performance in two end of year intermediate level maths GCSE papers.

Figure 7.2 Graph to show relationship between physics multiple choice score and maths score for my GCSE students.



Despite not being a perfect straight line, the results are encouraging since they show a positive correlation and hence a direct relationship. As a matter of interest, I also looked at how well the maths score correlated with scores obtained in other tests and exams throughout the GCSE course.

Figure 7.3 Graph to show relationship between performance in an earth and space multiple choice against performance in maths.



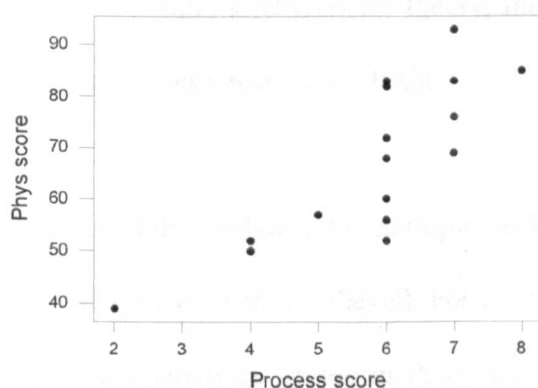
The correlation is 0.465 with a p-value of 0.001. The pattern of a correlation of between 0.400 and 0.600 was consistent for other comparisons between maths scores and test scores at GCSE level and this was also observed when the current AS level group was analysed from their data a year earlier.

Language and vocabulary

Preliminary work carried out concerning how an understanding of language correlated with physics exam performance also showed that there was a correlation of 0.605 (p-value = 0.001) for marks on a language test in comparison with physics test results. Generally speaking, a high exam performance correlates well with a good grasp of vocabulary, definitions, nomenclature and words relating to experimental method.

The link between physics ‘process’ and physics ‘content’ was also investigated at the preliminary stage. Students were asked questions about their knowledge of the physics syllabus’ content based on the topics that they had studied. They were also questioned on the nature of physics ‘process’ which involved questions concerning the design and implementation of investigations, apparatus, fair testing, observing, analysing, evaluating as well as the nature of validity and reliability of results. The correlation between physics ‘content’ score and physics ‘process’ score was found to be 0.803 ($p\text{-value} = 0.000$). This shows that the ability to produce good examination and test scores correlates highly with being able to design, produce and execute excellent investigative work. Being a highly investigative subject, thinking skills techniques, such as pole bridging, will be used in the thinking skills package and their effectiveness commented on in the main results section. The graph relating to this preliminary research is shown below:

Fig. 7.4 Graph to show relationship between performance in physics tests and investigative physics practical work.



Despite the belief that a positive correlation would be expected between physics test score and physics process score, it is still interesting to see the correlation between a dependence on the 'declarative' (knowing *that*) knowledge based on facts and the 'procedural' (knowing *how*) knowledge necessary for the performance of practical and investigative tasks. It might well be the case that procedural knowledge and declarative knowledge are inextricably linked. Anderson (1983) has suggested that the initial learning process involves the encoding of information declaratively, but with practice it becomes compiled into a procedural form. There are possible implications here for the involvement of a greater density of practical and investigative skills at all levels of physics education. The relationship between controlled and automatic processing for certain students where there are problems with attentional demand also needs to be addressed where there is disparity between students' declarative and procedural performance.

Multiple intelligences

In terms of 'multiple intelligences' theory, those questioned in years 10 to 13 gave the following preliminary results (N=100):

52% stated that they believed the multiple intelligences test had accurately predicted their type of intelligence, as they believed. For example, those who did well in languages and produced good language scores in their last exam sometimes found that the multiple

intelligences test indicated that they had 'linguistic' intelligence in abundance and less, perhaps, 'logical-mathematical' intelligence.

48% stated that the multiple intelligences questionnaire produced results that appeared to conflict with what they thought was their preferred intelligence, as they believed. For example, some highly mathematically minded students found that their mathematical score was not as high as 'musical' intelligence.

The students found the multiple intelligences idea difficult to accept and most (91%), when questioned, stated that the multiple intelligences model was:

- a) Oversimplified;
- b) Unsatisfactory in structure;
- c) Unsatisfactory to them as a predictor;
- d) Founded on poor reasoning;
- e) Of little use to themselves as learners.

The students did accept, however, that such an idea of multiple intelligences could exist, but in a far more complex form. Students commented that multiple intelligences could be useful when lessons are trying to teach 'invisible physics' such as electricity. Some suggested that the flow of electric charge could be made easier to the less mathematically minded via role play, CD ROM or other techniques. This preliminary research suggests that other, less popular techniques such as role play and pole bridging could allow other

pathways into knowledge that is often taught in the very didactic, mathematical and linguistic domains of intelligence.

Summary of main preliminary findings:

To summarise, the preliminary research provided the following information which was useful for the implementation section and subsequent main data:

- a) Some areas of the physics syllabus, especially at GCSE, are deemed more difficult than others. In particular, highly sub-micro and symbolic areas such as nuclear fission were deemed most difficult and this is in agreement with work performed by experts.
- b) Teachers and students agree about which areas are easy and which areas are difficult in the GCSE syllabus. The correlation was in excess of 0.8 ($p = 0.001$).
- c) Working memory becomes overloaded at between 6 and 9 items, with a very large drop from near 100% similarity to less than 1% similarity at 9 items. This trend was first noticed when a small sample was used in the preliminary research and it was strongly reinforced as the sample size increased over the two year research period. This conclusion was very similar to results obtained by Miller (1956), Johnstone (1992) and Newton (2000).
- d) Students know when they know key information or techniques and when they do not know key information or techniques surrounding the answering of questions. This finding indicates that the role of self-regulatory or metacognitive techniques

in education is highly significant. Again, this preliminary finding was apparent in the literature of experts in the field (Mestre, 2001).

- e) Students' confidence plays a fundamental part of their internal exam performance. Helping to create an atmosphere of confidence and self-regulation has a beneficial effect on performance.
- f) There is a close connection between how well students perform in maths exams and how well they perform in physics tests and exams. This would tend to suggest that improving a student's performance in maths by the use of appropriate strategies could also augment physics performance, too.
- g) There is a high correlation between physics content scores (class test results) and physics process scores (investigation results). This finding suggested that performance is not related to separate skills but to a global set of abilities that encompasses language, mathematics, metacognitive strategies and manual dexterity, amongst others.

Once these preliminary findings had been found, it was necessary to embark on the implementation of the thinking skills programme. These programmes, for GCSE and AS level have already been mentioned in the previous chapter. Before the programme was carried out at GCSE, all of those taking part were graded based on the Piagetian scale from early concrete to late formal generalisation thinking, that is from 2A to 3B on the thinking skills spectrum. This information was collected from materials used in class, based on Shayer and Adey's curriculum taxonomy, CASE and Thinking Skills materials in lessons and SRT's (Science Reasoning Tasks). This information was used to provide a

pre-test ‘snapshot’ of abilities which would be used later in the main analysis. A summary of the main pre-test findings are shown below.

Table 7.2 Piagetian stages of students before the implementation of thinking skills programme

Year Group	Early Concrete 2A	Mid Concrete 2A/B	Mature Concrete 2B	Concrete Generalisation 2B*	Early Formal 3A	Mature Formal 3 A/B	Formal Generalisation 3B
GCSE	9.1%	13.6%	36.4%	27.3%	13.6%	0%	0%
AS	0%	0%	0%	40.0%	46.7%	13.3%	0%

The values shown above are values for all of the students involved in the research in both the test and the control groups. For the GCSE groups (N=44), those figures shown are for both year 10 groups at the start of their GCSE course. The test that was conducted was the SRT (Science Reasoning Task) based on ‘Volume and Heaviness’ that the students had covered as part of their key stage three work in year 8. As can be seen from the figures, the majority of students lie in the stage 2B and 2B* at this stage.

The AS preliminary readings were taken at the start of the AS course, in September 2000. These results show that all of the pupils at AS level are at least at the 2B* stage of their learning. There are a significantly higher proportion of learners at the stages of 3A and above, as would be expected. Again, for comparative purposes, I decided to use the ‘Volume and Heaviness’ SRT that the GCSE groups had been given. In order to ensure

that level 3B was also available at AS level stage, students in the group were set class tests that tried to elicit answers that indicated learning and thinking was taking place at this level. The types of activity used are indicated in the table on the next page. None of the activities managed to show that students were consistently at 3B at this stage.

These preliminary readings do not show anything apart from a 'snapshot' of the Piagetian stage of development at the time when the data were collected. However, at the post-test stage comparisons will be allowed to be made both quantitatively, via statistical means, and qualitatively, via questionnaire and interview data.

In order to give access to the whole spectrum for all of those involved the following activity were tested, under the conditions stated in the table, showing the skills that were being tested along with the span of Piagetian levels involved.

Table 7.3 Tests used to diagnose Piagetian stages of development

Activity	Level of Test	Condition of Test	Piagetian Range
Fair Test	GCSE	Year 10 Exams	2A to 3B
Resistance of wire	GCSE / AS level	Coursework element	2B to 3B
Pendulum	GCSE / AS level	SRT demo in class	2B to 3B
Turning Moments	GCSE / AS level	Class practical	2A to 3B
Pressure	GCSE	Written questions	2A to 3B
SRT (Volume)	GCSE	SRT demo in class	2A to 3A/B

Those activities that are coloured in red are post-test activities and these were used after the thinking skills strategies had been employed to try and highlight any changes in the Piagetian stages of development.

As a means of comparison, results obtained from the preliminary research show that the students tend to agree well with the larger data set obtained by CSMS (1975-1978). The CSMS data shows that between the ages of 14 and 15, the average boy has reached a stage of learning between 2B and 2B*. For AS students, the average boy is at a Piagetian stage between 2B* and 3A, which is in agreement with data collected in this research. Despite the institute in question being 'selective', there is no strict policy that states that the selection process is based on an academic background. In fact, a number of the students in this research are classified as special needs and have learning difficulties. The institute could not be classed as being particularly selective and certainly not 'super-selective' in the case of most grammar schools. The cohort resembles that of a good comprehensive school which is recognised by most staff, parents and the whole senior management team.

Main Results Section:

Having conducted the preliminary research and found a number of interesting points, the next results section deals with the final data, obtained after the thinking skills strategies had been implemented.

The first piece of research conducted that was repeated was the 'difficult concepts' questionnaire where students were asked for their opinions on what was easy and what was difficult. The table below shows how these opinions have changed over the period of two years.

Table 7.4 Comparison between preliminary results and main results involving students' opinions about the easiest and most difficult areas of GCSE physics.

Hardest Topic	Easiest Topic	Hardest Topic	Easiest Topic
Nuclear Fission	The Plug	Nuclear Fission	Simple Circuits
Transistors	Renewable Energy	Radioactivity	The Plug
Radioactivity	Solar System	Seismic Waves	Renewable Energy
Life Cycle of Stars	Day, Night, Year	Transverse Waves	Magnets
Diffraction	Simple Circuits	Wave Equation	Solar System

The cyan columns refer to the preliminary findings from the Year 11 pupils who took their terminal GCSE exam in June 2000 and the blue columns are those data obtained from the Year 11 students taking their exam in June 2001. As can be seen there is a reasonably high level of agreement on both the hardest and the easiest areas from both

groups. Both groups agreed that nuclear fission and radioactivity were very hard and that the plug, simple circuits, renewable energy and the solar system were the easiest areas.

In terms of average values, the results obtained in 2001 were similar to the results collected in 2000. The two Year 11 groups used in March 2000 gave an average value of 3.57 for their five most difficult topics and the two Year 11 groups questioned in March 2001 gave an average value of 3.97. For the easiest five topics, the Year 11 groups from March 2000 gave an average value of 1.81, whereas the Year 11 groups of March 2001 gave an average of 2.15. On both accounts, the current Year classes, as a whole, deemed the most difficult and most easy topics to be more difficult compared with the previous year's students. Most importantly, how did the experimental group in the current Year 11 compare with the control group in the same year group? This is summarised below. In the final column of Table 7.5 there are two figures, quoted in bold, for the control group and the experimental group. The first figure refers to the average performance in the less demanding F-tier (Foundation) paper and the second figure refers to the average performance in the more demanding H-tier (Higher) paper. It is apparent from an initial inspection that the performances in the F-tier paper were very similar for the two groups with only a 3% whereas there was a 9% difference between the two groups on the H-tier paper.

Table 7.5 Experimental group versus control group for year 11 GCSE.

Group	Forces	Electricity and Magnetism	Earth and Space	Coursework	CRI	Average Exam %
Experimental	32.9	57.4	45.9	53.4	3.05	70%/56%
Control	32.2	51.2	43.3	50.4	3.85	67%/47%

These results show consistent outscoring of the control group by the experimental group.

The immediate question to ask would be: were the groups different in ability? The answer to this is 'no'. In order to see whether the groups were evenly matched, a statistical method known as discriminant analysis was used. Discriminant analysis involves comparing two sets of data from different groups and deciding whether a subject, picked at random, can be shown to belong to one group more than it does to another on the basis of probability. It then looks to see if the assigning of this subject to one particular group is correct a value from 0.00 to 1.00 is provided as a proportion of how correct the discriminant analysis technique was. The discriminant analysis technique provided a value 0.50, showing that a subject picked at random could only be said to belong to one particular group with 50% chance. In other words, the groups were perfectly matched in terms of their 'ability' before the thinking skills strategies were employed. The average examination results from year 9 for all subjects were used as the pre-test data in the discriminant analysis technique. However, an increase in the scores for the experimental group does not necessarily point towards a significant difference. To analyse whether the difference was 'significant' it was necessary to perform a t-test and look at the effect size.

The main findings are shown in table 7.6

Table 7.6 Effect size and t-test results for Year 11 mock GCSE examination data.

Group →				
Paper ↓	Control	Experimental	t-test values	Effect size
Foundation (F-tier)	The control group obtained an average score of 67% .	The experimental group obtained an average score of 70% .	T-value = - 1.1 p-value = 0.276	Effect size between groups was 0.25
Higher (H-tier)	The control group obtained an average score of 47% .	The experimental group obtained an average score of 56%	T-value = 4.3 p-value = 0.000	Effect size between groups was 0.76

The data in the table above summarises how the control and experimental group compared in the GCSE mock physics examinations. There is no evidence to show that the experimental group performed significantly better than the control group. This is indicated by the low T-value, the high p-value and the low effect size when the two groups were compared for the F-tier paper. In contrast to this, the results show a significant difference between performances on the more difficult H-tier paper. This significant difference is shown by the high T-value, the very low p-value and the large effect size. These results would suggest that whilst the thinking skills programme has not

made a significant difference for the easier F-tier paper, it would appear that the thinking skills programme does allow students to produce better scores on the more difficult H-tier paper.

How did perceived difficulty compare for different topics between the control and experimental group? There were some fairly startling differences between perceived difficulties when the two groups were compared. As stated in the implementation chapter, there were a number of strategies that were employed over the two-year course. A table showing these results is shown over the page. As a sample, some of the 36 areas that were most appropriate for analysis are included. The closer the value is to 5, the more difficult the topic is perceived to be.

Table 7.7 Perception of difficulty for experimental and control GCSE groups.

Topic	Experimental value	Control value	Strategy used
Ohm's law	2.60	3.38	Pole bridging VAKi
Big Bang	2.60	3.31	Chunking, KWL Concept Mapping
Life Cycle of Stars	3.20	3.63	Chunking KWL

			Concept Mapping
EM Spectrum	3.00	3.50	Chunking Mnemonics Hospital-House idea
Seismic waves	3.25	3.88	Simple Word Associations.
Radioactive decay	3.75	4.19	“Unhappy Melons” story Chunking Concept Mapping

Qualitative data responses:

Having collected numerical data, the next step was to find out why the differences occurred based on the opinions of the students themselves. For each of the above examples, condensed comments from the interviewees will be used.

Ohm’s Law:

“I found the VAKi model useful because you could ‘see’ what voltage, current, energy and resistance were like by using a role play idea. The idea of a smartie being energy that is carried by mr. Charge who makes up current etc.. being pushed by the mr. Potential difference who does not move was a good model. It helps me picture those terms when I look at questions that involve circuits.”

"The pole bridging technique was really useful. I used to hate making circuits and never knew where to place the ammeter and voltmeter, in fact I did not know what series and parallel was..it was like another language. By talking myself through and realising that I did not need the voltmeter in the circuit for it to work, I realised that it must go in parallel. Small things like that seemed to make big differences to my understanding of the topic .It wasn't the calculation that was hard it was more the stuff before that confused me...all those invisible things...current, charge, voltage...I mean...what's all that! I sort of see it more now."

Big Bang / Life Cycle of Stars:

"I thought that this would be quite easy, but there was loads of big words and I couldn't get my head around them! The chunking thing was useful because it meant that I could concentrate on small lists of words rather than plough through all my notes. Once we had kept going over the words, I could put together my concept map in chunks of six or seven key words. It's much easier now when I look over it."

"The KWL technique was good, especially with the video. The video was great!"

"That concept map sheet we had to fill in was good, cause you see how it all fitted together and it was all on one page, which means I don't have to read loads of notes."

Electromagnetic Spectrum:

"There was a lot to learn here! All that gamma and infra-red and ultra-violet stuff. I didn't get it at first, but the hospital-house idea made it fall into place. Now I know that the house stuff like Radio, Microwave, Toaster and TV are at the safe end and the Gamma rays, X-rays and UV lamp are at the dangerous end. Now it makes sense, and the VAKi method of closing your eyes and walking through the house and hospital really works. I still don't get that $v=f\lambda$ stuff though!"

"Using mnemonics helped me remember all that stuff. My one goes 'Ray and Mike read some light stuff to violet and her ex eating gammon'. God huh? I can even see her when I say it...it's weird!"

"I use a mnemonic thing, but it's too rude to repeat!"

"I did a concept map with small chunks of knowledge coming off each bit. The mnemonic thing doesn't work for me, I can't think of a good one to help me remember!"

Seismic Waves:

"I just remember: primary school before secondary school, so p-waves reach before s-waves! Good wave of doing it. I can't remember if they're transverse or longitudinal though!"

"I have cracked the p before s idea, but trying to remember the rest is still hard."

Radioactive Decay:

"I thought Mr. O'Neill had lost it when he started the lesson by talking about 'unhappy melons', but it worked in the end. The large unhappy melon spits out pips until it becomes an unhappy grapefruit and then it spits out other pips to eventually become a happy plum! Now I can see the idea of alpha and beta particles being ejected by 'unhappy' atoms that want to become stable."

"That unhappy melons stuff was okay, but I just preferred to do a key words list using a small concept map, one for alpha, one for beta and one for gamma, with seven items on each."

"The unhappy melons idea was all right, but the CD ROM we used on the whiteboard had more of an affect on me."

Evidently, the thinking skills strategies had a lasting impression on a number of pupils in the experimental group and they agree that it has allowed them to grasp some of the most abstract material. The majority of the students also commented that the funny nature of the unhappy melons and mnemonics ideas helped them understand the topics and that they had built up visual pictures of the concepts in their heads which remained with them throughout the course.

Although the Year 11 responses for perceived difficulty were higher in 2001 than they were in 2000 for the whole cohort, there was a difference between the 2001 Year 11 experimental and control groups as shown below.

Table 7.8 Perceived difficulty for experimental and control groups at GCSE, 2001.

Year 11 Group, 2001	Average Difficulty score
Experimental	2.90
Control	3.10

As shown in the table, the experimental group had a lower average value for their perceived difficulty of the syllabus as a whole. In the areas where the thinking skills strategies were used these values were significantly lower.

Main Results with Year 10 GCSE groups:

The Year 10 GCSE experimental group were given a teaching programme as discussed in the implementation chapter. This 7 week course was delivered in the first half-term of their Year 10 course and then data was collected in the form of questionnaire, interview and Year 10 examination results (December, 2000). As a preliminary measure, the two groups were again compared via discriminant analysis and this time there was a marked difference between the two groups. The discriminant analysis this time showed that the group that was to be the experimental group (taught by myself) was in fact of a higher ability than the other group that would be taught by another member of staff and would,

therefore be the control group. By looking at previous results in other subjects and in physics, it was seen that the average result on examinations varied by 6% on average over the previous three years. This 6% value remained remarkably similar over the key stage three period.

The teaching programme mentioned in the previous chapter was delivered to the Year 10 experimental group (N=16) and the control group (N=22) was taught by another member of the department using no teaching skills strategies. The other member of staff was made aware of the thinking skills programme and the need for objectivity so that there was always a 'pure' control that did not experience the thinking skills strategies. Each week, lesson plans were compared and there was a comparison between work done by the experimental class and the control group to ensure that there was no corruption of the methodology. At the end of the teaching skills programme, the Year 10 students were given their Christmas examination and the following results were obtained:

Table 7.9 Research carried out with year 10 groups following GCSE Physics.

Year 10 Group	Exam Average	Electricity Test	CRI value
Experimental	70.1%	56/75 (75%)	3.5
Control	56.4%	42/75 (56%)	3.0

In the main Christmas examination, the average group score increased from a difference of 6% based on previous results to a difference of 13.7% after the thinking skills strategy

had been implemented. There is also an increase in the average electricity test score after the 7 week thinking skills programme had been implemented.

Table 7.10 Effect size and t-test results for 1999-2000 Year 10 control and experimental groups taking separate science GCSE Physics.

Group Paper	Control	Experimental	t-test values	Effect Size
Common Physics paper (containing F- tier and H-tier material).	Control group achieved an average score of 56.4% on the common paper.	Experimental group achieved an average score of 70.1% on the common paper.	T-value = 2.74 p-value = 0.01	Effect size between groups was 0.84 .

Table 7.11 Effect size and t-test results for 1999-2000 Year 10 control and experimental groups based on end of 'Electricity' test after delivery of Thinking Skills programme.

Group Paper	Control	Experimental	t-test values	Effect size
Electricity Examination (multi-choice)	Control group average was 56%.	Experimental group average was 75%.	T-value = 5.35 p-value = 0.000	Effect size between groups was 1.33

The results in tables 7.10 and 7.11 indicate that there is a significant difference between the performances of students in the experimental group with respect to the students in the control group. In both cases, students in the experimental group produced significantly better scores than their control group counterparts. The effect size for the 'Electricity' test data was unusually high, suggesting that the experimental group's performance is well in excess of one standard deviation greater than the control group's performance.

As mentioned, there was an initial difference between the two groups of 6% based on the average exam score obtained at the end of year 9. However, a significant increase of 7.7% to give an average difference of 13.7% would suggest that the thinking skills programme might well have had a significant effect on the learning of the electricity work over the seven week period, despite this initial difference. Even when the initial 6% difference is taken into consideration with the electricity test results, the effect size is still 0.91. This would still indicate that the experimental group has performed significantly better than the control group.

In order to determine whether the thinking skills programme had made a difference, I administered a questionnaire and conducted selected interviews based on some of these responses. The table below contains quantitative data from the questionnaire pertaining to the perceived usage and effectiveness of the thinking skills strategies used in this part of the research. GCSE students provided the data from within my institution.

Table 7.12 Responses to thinking skills effectiveness questionnaire.

Thinking Skills Strategy	Percentage of pupils familiar with strategy	Percentage of pupils who have used the strategy	Percentage of students who found strategy effective
VAKi	100%	100%	88%
Key Words	100%	94%	81%
Pole Bridging	100%	100%	88%
KWL	100%	75%	69%
PMI	100%	88%	44%
CRI	100%	100%	81%
Wrestling Maths	100%	25%	25%
Concept Maps	100%	100%	81%

The first column in the table shows that all students managed to recall the thinking skills strategies that had been delivered. The second column shows the percentage of students that have used the strategies, in any context, on a number of occasions and the final column shows the percentage of students who stated that they thought that the strategy was of particular use to them as an effective learning aid.

The qualitative responses gathered from questionnaire and interview material in the specific thinking skills, along with general comments are shown below for the year 10 cohort.

VAKi:

"The VAKi strategy was very useful in class when we did about circuits. I liked it because I didn't get what some of the words meant at first. The Mr. And Mrs. Charge thing was good. By acting it out I could 'see' what was happening. This made it easier to solve my circuit problem in the exam when I needed to find the values of current in the branches in the circuit."

"When I came to revise a topic in my revision, I could remember the work covered in that topic because I linked it to the fun stuff we did in the lesson. The work 'matched up' with the (VAKi) stuff that we did in class; it's better than just copying from a book."

"I found the VAKi strange at first, but I got into it. The idea of seeing, hearing and acting out the work seems obvious now, but it didn't at the time. Now, when I do exam questions I see the acting out that we did in class and the charge, current, potential difference and energy ideas seem to fit together...it's a bit like watching a video in my head!"

The VAKi technique proved popular in the year 10 group. The experiments did lend themselves to this technique, since the sub-micro elements could be modelled quite effectively and turned into a macroscopic strategy that made the learning of the ideas of electrical current, charge etc., more manageable.

Key Words:

"The key words idea is useful at the end of the lesson. I like to think that if I know the key words then the other stuff can be 'filled in' around it."

"Using my highlighter pen to colour key words because the 'real' physics stuff that I need to know stuck out and the other words like 'the' 'if' 'and' and other words I didn't need to know were just forgotten! It was great, I felt as though I was learning all the hard bits without doing any work!"

"When we went back to keep adding to and testing our key words was helpful. It just stuck!"

"We have these colour coded key words stuck around the class. They are good for cheating in tests, but I think that's the idea anyway!"

"I like the key words thing for organising words. I do the story idea by putting a few words in order and then stringing them out into a story or method. I do sometimes worry if I've missed anything, but I agree that the key words and mnemonics idea is useful."

A high proportion of the students commented on how useful they found the key words idea. Most students used it as a simple list or via a mnemonics list in which they constructed a story from a few key words. Other students remembered the colour coded words in their positions around the classroom and others used keywords to construct simple spider diagrams before going on to construct more complicated concept maps.

Pole Bridging:

“The pole bridging was really weird at first; I felt really stupid talking to myself. I was really embarrassed. After a bit, we did it where we closed our eyes before the practical and just acted out the putting together of the circuit. When we had used it a few times it didn’t feel so strange. I would only use this in my investigation work, not for notes and homework.”

“I thought pole bridging was great: it made me talk back to myself and think about ‘why’ I was building the circuit in a certain way. Instead of calling for sir when we got stuck, we kept going until it worked by saying ‘it doesn’t work! Maybe it is the wire that is broken’. It was useful.”

“I now realise why you put the ammeter in series and not in parallel!”

The pole bridging was very successful in practical classes, even if a little noisy at times. The students turned it into a fun exercise by purposely making the circuit incorrectly so that they could comment on their errors. The metacognitive self-reflection aspect of the exercise did tend to get the students looking at the ‘why’ behind the physics. Many questions were posed such as: ‘why does the light not come on?’ ‘why does the ammeter not work?’, ‘why doesn’t the voltmeter go in series?’ etc.

The students found that this was a good technique to use on certain occasions, but some students thought that over usage could be ‘boring’ and, therefore, unproductive. I agree that over usage could detract from the effectiveness, as the thinking skills strategy would no longer be a useful tool but more of a repetitive chore.

KWL:

“I thought the KWL was useful for when we watched videos, but no use anywhere else, really!”

“The KWL was okay for videos, but I couldn’t keep up with the video at times and so I might have missed information. I would have preferred to just use key words to be honest.”

“The KWL was good, but I didn’t know much I should have written.”

KWL had a mixed reception; some liked it, some didn’t. The most popular comment was that it made them pay attention to video work, especially when the teacher was rewarding the students with rewards for the most high quality responses! However, over usage and use of KWL outside of physics lessons that involved video material or CD ROM was not found to be as effective as other strategies.

PMI:

" PMI was a good idea, because it made you think hard about possible answers that you might not have looked at before."

" When we first did the PMI work it was really good, because we had never done it before, but it was only safe to use when the teacher was around to tell us if we were right or wrong."

"PMI was good, but after a while I would dry up and start to run out of ideas. It was good when Mr. O'Neill set us a few PMI questions for homework and gave us a few hints".

The PMI strategy was a good metacognitive technique, allowing pupils access to their current state of learning immediately. When students were given a PMI to do every lesson it became a fairly well accepted technique and these could be differentiated in terms of content, both physics-based and in terms of language content. Usually, PMI strategies were offered as being relevant to 'all', 'most' or 'some' pupils with the level of sophistication being in that order. So a low level PMI for the 'all' candidates would be:

Do a PMI on why coal may or may not be as good as wind turbines.
--

Where, at the 'some' level of sophistication would be:

Do a PMI on what could possibly happen if the mass of the sun was bigger by about 40%.
--

The level of sophistication is proportional to the degree of sub-micro level physics in the question and the extent to which it can be manipulated or interpreted. It is important to accept, when using PMI, that certain pupils at the lower end of the ability range will not necessarily be able to answer PMI questions as effectively as those pupils who have a greater knowledge.

PMI was accepted as being useful, as having numerous answers and having an infinite number of questions that could be delivered at many levels. Again, over usage was seen as detrimental since less time was being spent on delivery of important content and too much time being used on thinking skills strategies. Usually, a PMI was given as a homework once a week, but this would not always need to be the case as saturation of a technique tends to cause it to lose its effect.

CRI:

“ I thought the CRI thing was good for letting me know what I know!”

“The CRI thing was quite good. When I look back on the previous tests that I did, I notice the ones where I have made progress, because my CRI score gets better, so I must be getting more confident.”

“It’s a common sense thing really, just being honest about what you don’t know. It is useful when you look back at the CRI values so that you know 5 or 6 areas that need major revision. I can look at them and not get too stressed out by thinking that I have to

look over all of my work, because I don't! All I really need to do is look over the stuff where my CRI values say I am not confident."

The CRI strategy was used by a large number of the group effectively and it has been used sensibly as shown by comments made above. Students generally experienced these CRI techniques as part of end of topic multiple-choice tests. However, many students also employed the CRI as part of their work at home, without this actually being suggested. The CRI was accepted as being a very useful metacognitive strategy which was employed with very little immediate cognitive demand. Since the technique placed such low demand on students' working memory, the CRI technique was both popular and well used.

Wrestling Maths:

"The wrestling maths idea worked for me because I cannot do maths. By remembering the 'top dog' idea I can decide which way to arrange the equations."

Most pupils were actually quite competent when it came to rearranging equations of the form $V = IR$. Transposing equations was usually done by remembering that 'V' was 'top dog' and so always went on top. However, most pupils could remember that $R = V/I$ or that $I = V/R$ without utilising the technique, but a number ($N=8$) did admit that the wrestling image did reinforce the equation due to the 'visual' area being used as well.

Concept Maps:

"Concept maps are very useful for putting a large amount of information on one sheet of paper. Then, when I look at it again, all of what I need to know is on one small sheet. This method means that I don't panic as much at the end of the topic because I have got rid of all the stuff I 'don't need' and I am only revising the stuff that I do need."

"I wasn't that keen on concepts maps at first, but I like them now. What I do now, instead of doing one big map, I do about 5 or six really small ones with only about 7 bits of information on. When I do this, I do each one in a different colour and I make the sheet stick to one area of the syllabus. So, I will do one orange sheet on symbols, one blue sheet on equations, one green sheet on forces until I have covered everything I need to know. Also when I revise, I flick through the cards and only do a few at a time, so that I don't get bored."

Concept maps were a very popular strategy, but they did have to be adapted to suit the demands of students who had problems learning large amounts of information. This tended to suit all children to a large extent, although more able students did like to chunk the information in larger numbers, such as 7 or more, whereas lower ability students would only cope with 5 or less items. They were a popular thing to do as display work and were also used in the lesson as a means of key information retrieval.

Some of the most able students did complain, however, that sometimes this method of truncation was possibly a disadvantage as some key information could be accidentally neglected. These students did tend to produce over elaborate concept maps that I

considered to contain too much information for one map, so this was often made into two or more smaller and more manageable maps.

As a summary of the findings for the current year 10 groups, I believe that it is safe to say from the quantitative and qualitative evidence obtained and from the difference in the average examination performance of the two year groups, that the thinking skills programme has been a success. The vast majority of the students in the experimental group have used these strategies and they have stated that these thinking skills strategies did make a definite positive contribution to their learning and to their examination results. The data shows that the thinking skills strategies did augment learning and allow the more difficult concepts to be visualised.

Main Results with Year 12 AS level group:

The method of results collection for the year 12 group differs from the method for the GCSE groups in the fact that there was not a parallel control group because the timetabling within the school could not support this. Despite the fact that the numbers of students taking physics at post 16 has risen from one student to fifteen students in four years, there has still not been enough sufficient numbers in my sixth form for the timetable to sustain two groups. One of the difficulties when conducting the research was trying to obtain control group data from another school. Only one institution agreed to give access to their sixth form results, but, unfortunately, the modular course was not the same as mine and some comparisons could not be made as too many other variables

would have been introduced. Such variables included examination board, examination modules and the amount of time spent on the course. Also, the course in my institution did not involve a similar practical-based approach that was a mandatory component of the other institution's course. With too many variables, it was decided that the approach at AS level would be conducted on a more ipsative level. Ipsative assessment involves the rating of a student's current performance in relation to previous performance rather than a comparison with set 'national' criteria or a normal distribution of the whole population. This style of assessment can be commented on by the teacher in qualitative and quantitative terms and it can be used to improve confidence of students, especially when prior performance has been poor. Subsequent monitoring of students' performance, once the course has been delivered and the first examination module has been taken, can be monitored via ALIS data and this is mentioned later on in this chapter.

Instead of having two groups, one experimental and one control group, I have decided to analyse the data in two ways. Firstly, I will compare the results obtained in the AS modular exam with results obtained at GCSE and, even further back, to the Yellis data collected before the GCSE examination. Secondly, I will analyse the data collected from questionnaires and interview to see if there is any agreement between students as to the nature of the content of the syllabus in terms of its relative difficulty and also to determine the effects of the thinking skills strategies employed. The quantitative methods used involve calculation of mean values, residuals and Pearson correlation with associated p-values.

The first questionnaire results concerned the perceived difficulty of the major constituents of the first AS level module entitled 'Particles, Radiation and Quantum Phenomena'. The questionnaire was delivered at the end of the topic, once the thinking skills programme had been delivered but before the students had sat the examination module in January 2001. As with previous questionnaires, the first question involved students grading the difficulty from '1' which represented 'very easy' to '5' which represented 'very difficult'.

The results below show the average responses obtained from within my institution.

Table 7.13 Perception of difficulty for nine areas of an AS physics module

Area of Module	Average Perceived Difficulty
Rutherford's Model of the Atom	1.79
Hadrons, Baryons and Leptons	2.79
Feynman Diagrams	3.00
Conservation Laws	2.57
Photoelectric Effect	3.07
Electron Diffraction	2.93
Refraction and Total Internal Reflection	2.21
Atomic Spectra	3.14
Photon Energy	2.93

The general trend which can be interpreted from the values in the table is that the more macrophenomena style content is perceived as being easier, whereas the more micro

phenomena and symbolic content was seen to be more difficult. The most difficult area, atomic spectra, is highly symbolic and sub-micro, involving difficult models and mathematics to explain a quantum effect that is much removed from mundane experience. The comments that were made by the students concerning the content were as follows:

"I thought that the Rutherford scattering topic was the easiest because you only had to learn the information and not really understand or apply it."

"I thought that refraction and TIR was easy because you could 'see it' when you did the practical. Also, I had done this topic at GCSE so I already knew it quite well."

"The work on photon energy was easy because it was just one equation $E = hf$."

The comments made above are examples of those comments concerning the perception of the easier work. The main pattern was that the Rutherford model of the atom was probably the easiest topic because it was easy to visualise, it had been done before and it did not contain any maths.

The comments concerning the most difficult areas are given below:

"I found the atomic spectra difficult because I did not understand what it was about. Why do you have these lines and why is light given out. There was an equation involved also, but that just confused me even more."

"I thought electron diffraction was hard because how can electrons be diffracted?"

"I thought Feynman diagrams were difficult because they all looked the same and I did not get why you had to draw them in that way; it was weird."

"I thought Hadrons, Baryons, Leptons and Mesons were hard because I had never seen them before and it did not fit in with the stuff I did at GCSE in physics and chemistry. The facts involved all these strange words and they had to be learned perfectly. For example, I got confused between a lepton and a quark and which ones made up baryons and all that new stuff. I got it in the end when I did some concept maps, but it took some doing."

In terms of effectiveness, students in year 12 were asked to give their opinions as to the effectiveness of the various strategies. In particular, students were asked to comment on the following points, concerning each strategy and its relevance to the teaching and learning of the physics syllabus at AS level:

- a) Had they heard of the strategy?
- b) Had they used the strategy?
- c) Was the strategy useful?

The following results were obtained:

Table 7.14 Response to thinking skills effective questionnaire from AS students in my institution.

Strategy Employed	Had they heard of it?	Had they used it?	Was it useful?
Concept Maps	86%	71%	29%
PMI	71%	29%	0%
KWL	79%	71%	21%
CRI	71%	50%	29%
VAKi	71%	57%	29%
Reinforcement	100%	100%	100%
Pole Bridging	57%	21%	21%
Question Writing	100%	86%	43%
Metacognition sheets	93%	64%	50%

The results show that the strategies have been employed to varying degrees and subsequent comments made by students as to the strategies' relative successes are also varied. Some of the most relevant comments that were made have been included below.

The 'effectiveness' of each strategy was not initially defined by myself as a measure of some particular outcome, such as examination score or understanding of the syllabus, but more of a personal measure by the students as they perceived it. The subsequent interviews with AS level students did eventually lead to a global perception of 'effectiveness' that will be summarised later on in this chapter.

The results shown in table 7.14 suggest these results:

1. Re-inforcement, the continuous returning to work lesson by lesson on a cumulative scale, has had by the far greatest positive response by students as to its 'effectiveness'. All of the students questioned in my group (N=14) had heard of the technique, been exposed to it and found that it was useful. Reinforcement involves the continuous use of the same questions within a topic to reinforce knowledge. A CRI is used each time for self-regulatory purposes.
2. Certain 'Thinking Skills' techniques such as KWL, concept maps, CRI and VAKi were known to students, had been used by many of them but found to be less useful than others, particularly reinforcement.
3. PMI, despite being a strategy that is perceived as reasonably useful amongst the younger GCSE students, is perceived as being useful by none of the AS level students in this study (N=14).

The results could indicate, from the quantitative data, that students are not using the strategies as much as they 'should' do. Also, the results could indicate that some of the strategies are not particularly 'effective'. Alternatively, the results might suggest that the students are not entirely familiar with the strategies, are not comfortable with using the strategies and, because of this, do not find them as useful as their true potential would possibly suggest.

To try to ascertain the collective idea of ‘effectiveness’ as viewed by AS level students in the sample, and their personal beliefs concerning the thinking skills strategies, interviews and questionnaires were administered to augment the quality of the data collected. Some of the more lucid responses concerning the main aspects of the AS level research are given below. In order to make the results more ‘accessible’, the responses have been grouped into particular areas of interest with each area represented by a question. These areas were the ones that became apparent whilst this secondary stage of the research was being conducted.

‘What do you understand by the term ‘effective’ in this study?’

“ If I ‘feel that I know it’, then the strategy is ‘effective’. What I mean is, has this strategy allowed me to add new knowledge to what I already knew and is the new knowledge going to ‘stay there’ in my head? Sometimes, the more complex things like PMI sound like a good idea, but they don’t have the same effect as doing something simple like just doing ‘reinforcement’ tests.”

“ If I am confident that I know something enough to be able to answer any exam question on that subject, then the strategy is effective. Physics is more than passing exams, of course it is, but passing exams means that I spend more time on learning content that is relevant for the exam and less time doing thinking skills techniques.”

"Doing things in class that act as models for my learning is 'effective'. I like to see things in pictures and movement rather than just text. I find something 'effective' if the model allows to me understand it better than I did before by visualising it clearly."

"I think a strategy is 'effective', if, after I have used it, that strategy allows me get better marks in a test in class."

"An 'effective' strategy is when you realise that what you knew before was wrong!"

"Some things like the 'metacognition sheets' are really useful in terms of what you don't know, but I think 'effective' strategies, for me, are ones that give you new information that lets you improve what you do know. I mean, you can add to what you already know and you can improve what you already know. Then, you should do better in tests and get a good grade!"

'When were the strategies effective if at all?'

"We often used strategies in class and they were effective when we had guidance. Reinforcement was by far the best, with small chunks leading on to larger chunks once we had learned enough of the syllabus."

"I found pole bridging and VAKi useful when we were doing practical work, but it was no use outside of the classroom. I could remember the VAKi techniques used to model physics, but I could not make 'the leap' to invent ones of my own; it was too hard!"

"The 'question sheets' where you had to invent your own question and mark scheme were really useful when you got feedback, especially straight away, with some help! When I did my own at home I was less confident and it was frustrating, so I often gave up and just revised from texts."

"The concept maps were useful inside and outside of the classroom. Once I had accepted the idea that the facts could be linked together, like a jigsaw, I soon got into the habit of doing this. I found that adding new knowledge sometimes meant destroying old concept maps to make more refined ones. I was happier when these maps were checked, however."

"The 'metacognition sheets' were useful for letting me reflect, and it made no difference whether we did this in school or as a homework exercise. However, they only told me what I didn't know, so they weren't the best for self-belief!"

'How could the strategies be made more effective?'

" Something like reinforcement is extremely useful and is made more effective by having the same format each lesson, but with slight variations to the questions. However, the underlying physics stays the same."

" I really like concept maps, but I wish we had been given them when I was younger so I could feel more comfortable with them."

" PMI is good when we get specific examples, but I just cannot be bothered to do my own! It takes so much energy simply trying to think up the questions, never mind try and perform a PMI on them! If we had a small number of really good ones from the teacher then it might be more popular."

" This whole thinking skills thing really confuses me! I only really understand the answer once it has been explained. When I have to try and think myself it's like someone has switched my brain off! I can see that it is a good idea, but should we not come into contact with sort of learning when we're about four years old rather than leaving it until I'm 17?"

" The strategies could be made more effective by using them at 'key' stages during the course. If we use them all of the time then they lose their effect; similarly, under-usage

allows them to tantalise us without having a long-term effect. Apart from this, I cannot really comment, maybe more research into the area is needed."

" I like some of the thinking skills ideas we use, but some of them need to be made more relevant to the final aim of achieving a good A-level grade. I remember using the VAKi model to help me answer some questions in the exam and the key words technique was definitely a neater way of getting me to learn definitions and other stuff that was purely 'learn and churn'. However, apart from these four or five extra exam marks I think I got in the exam, the thinking skills did not effect my exam performance that much. Where I think I did benefit is when I attempt to explain to other people the physics involved, it has made my knowledge better, which I suppose is good!"

'Why are some of the strategies better than others?'

"The end result is a good grade. Some strategies help me get a good grade and some are just a waste of valuable time!"

"The best ones are those that 'don't hurt'. I like the 'hospital-home' model for remembering the electromagnetic spectrum because it is easily visualised. Mnemonics are good because they don't demand a lot of thinking and concept maps mean I can get a large amount of the key things down on a page or two. I suppose what I mean is that the best ones are those that are the most 'efficient'! You put a little effort in and you get a lot of well-structured knowledge out!"

"Some strategies are better than others when the 'penny drops'. The concept maps are useful, but they are more a way of 'organising' work and less of a 'success' in the teaching of work. On the other hand, VAKi is useful because you can see, hear and act out these abstract terms such as charge and current. For me, this let me 'see' the ideas in action and so the physics fell into place."

'Who could help make these strategies more effective?'

"It is the job of the teacher to expose us to these thinking skills. Teachers, as professionals, have this knowledge which they can teach us to use for ourselves."

"The government has written a national curriculum for all schools. Should the same thing be done with the inclusion of these special learning activities?"

"One of the problems with these thinking skills strategies is that there don't seem to be any really good ones that are in standard usage. The CASE material is useful, but not perfect and some of the other skills sort of 'lead you up the garden path' without a final target that you feel you have achieved. I would like a course of really appropriate activities that are a real challenge, but also something that feels as though it has 'opened my eyes' to the subject. Maybe someone could write a book with a number of really good thinking skills activities in it that fit into what we have to learn?"

"My friends do thinking skills in their school in a number of subjects, not just science. My mum works as a teacher at this school and she says that they have INSET courses where two speakers come in and deliver a whole-school course to staff. Why can't we have one here?"

How do these results have significance in terms of examination performance at GCSE and AS level?

Collecting data for the AS level section of this research was made difficult due to a number of variables. The major one in my school was the fact that the sixth form only contains 30 students, although half of those have studied physics at AS level. Other problems involved the lack of access to sixth form institutions that followed the same AS level course as my institution and their willingness to act as a control group in this research.

Despite the presence of fairly sophisticated statistical techniques that can (partially) account for these differences, such as discriminant analysis, the construction of a high quality fair test would have proved too difficult and could have shown low validity and reliability values. To help solve this problem, I decided to compare my results at GCSE and AS level with those on a national basis by making use of Yellis data and ALIS data.

Luckily those students who were taught at GCSE level are now being taught by myself at AS level. The GCSE groups were split into a control group, taught by a colleague via a non thinking skills approach and the experimental group, taught by myself where the thinking skills strategies were employed. The two groups at GCSE can be analysed by using the Yellis data that our school makes use of. For ethical reasons and because confidentiality has been promised to the students and the head of the institution, neither the institution name nor the names of any students will be mentioned in this chapter.

The tables below show how the experimental and control groups compare. The first table shows how the students performed in the experimental group, whereas the second table shows how the students performed in the parallel control group.

Table 7.15 Residual scores for experiment group GCSE students based on Yellis data.

Student	Predicted Grade	Actual Grade	Residual
Exp #1	5.4	6.0	0.6
Exp #2	6.1	7.0	0.9
Exp #3	6.9	7.0	0.1
Exp #4	4.7	4.0	-0.7
Exp #5	7.0	7.0	0.0
Exp #6	4.7	6.0	1.3
Exp #7	6.4	8.0	1.6
Exp #8	5.7	6.0	0.3

Exp #9	6.5	5.0	-1.5
Exp #10	5.6	6.0	0.4
Exp #11	6.5	7.0	0.5
Exp #12	5.6	4.0	-1.6
Exp #13	5.2	7.0	1.8
Exp #14	6.4	7.0	0.6

The table below shows the results corresponding to the control group where no thinking skills strategies were used:

Table 7.16 Residual scores for control group at GCSE based on Yellis data.

Student	Predicted Grade	Actual Grade	Residual
Control #1	4.5	3.0	-1.5
Control #2	6.0	5.0	-1.0
Control #3	4.8	4.0	-0.8
Control #4	5.5	5.0	-0.5
Control #5	4.1	4.0	-0.1
Control #6	5.4	6.0	0.6
Control #7	5.1	8.0	2.9
Control #8	6.7	7.0	0.3
Control #9	5.5	6.0	0.5
Control #10	5.9	6.0	0.1

Control #11	5.3	6.0	0.7
Control #12	5.8	6.0	0.2
Control #13	5.1	6.0	0.9
Control #14	6.5	6.0	-0.5

The results show an average residual of 0.31 for the experimental group and an average residual of 0.13 for the control group.

Whilst both tables show that, on average, the experimental and control groups have positive residuals, which indicates 'value added', it is the thinking skills experimental group that had the highest residual. As a reference, a residual of +1 means that a student has achieved one grade above his or her predicted grade based on the student's in two tests compared with the performance of other students in the survey. Similarly, students who achieve a residual of -1 means that they have achieved a grade that is one grade less than they have been predicted and so have not had value added to their education. The results obtained by the experimental group of a residual of 0.31 means that students are achieving about 1/3rd of a grade higher than they are predicted. This is greater than the value of 0.13 obtained from the control group data.

The significance of the Yellis data is that it offers some indication of how students are performing in my institution compared with other students in physics on a national basis at GCSE level. This allows external validity to be given to the findings. The reliability of

the Yellis data is increasing over time as a greater number of schools become involved in the project and as more centres pass through the Yellis process each year. The Yellis data obtained so far would appear to indicate that the thinking skills strategies used so far have had a positive effect on the learning of students in my institution and that it compares favourably with students nationally. Currently, 260,000 students' responses are used by Yellis each year, increasing the reliability of the quantitative analysis performed.

The Yellis data that has been used in this research is also applicable to the AS experimental group. Those students who provided the Yellis data are currently in the AS physics group that was used in the research. How well these students performed once the AS level thinking skills programme had been delivered can be analysed, to a certain degree, based on how well students perform at A level compared with their GCSE performance. The ALIS data that allows such predictions to be made does not involve my teaching institution, but the information that it provides is of use to this research.

Fundamentally, ALIS uses Yellis data as a predictor to how well students will perform at A level. Despite the change in A level structure, ALIS should still be a good indicator to AS level success based on GCSE performance. The ALIS system states that the best indicator of performance in the A level examinations is not the individual grade in that subject at GCSE but the average GCSE performance in all subjects.

In particular, the regression equations that have been supplied by CEM, based at Durham University show that for the modular physics A level examination the relationship is given by:

$$\text{Predicted grade} = (\text{Average GCSE grade} \times 2.73) - 11.44$$

So, based on the Yellis values, an A* grade is worth 8 points, an A grade 7 points, etc., down to a U grade being worth 0 points. The ALIS system is based on the UCAS points system where a grade A at A level is worth 10 points, a B is worth 8 points, etc., down to a U grade being worth -2 points.

Theoretically, a student who obtains an average of grade B at GCSE, based on the regression equation, should achieve a grade D at A level based on this calculation:

Av. GCSE = grade B = 6.0 points

Predicted A level grade = (Av. GCSE \times 2.73) – 11.44

Predicted A level grade = (6.0 \times 2.73) – 11.44 = 4.94

4.94 corresponds to a grade that is approximately half way between a D and a C grade.

The Average GCSE grade is used in the model because it was found to be the best predictor of A level performance, better than individual performance in that subject at GCSE.

The following table contains the data that is appropriate to the AS level group in question:

Table 7.17 Residuals for AS level group based on ALIS data.

Student	Average GCSE	Predicted A	Actual A	Residual
AS #1	6.00	4.94	4.00	-0.94
AS #2	6.10	5.21	8.00	2.79
AS #3	6.60	6.58	10.00	3.42
AS #4	6.55	6.44	8.00	1.56
AS #5	6.00	4.94	8.00	3.06
AS #6	6.45	6.17	6.00	-0.17
AS #7	6.10	5.21	8.00	2.79
AS #8	6.50	6.31	10.00	3.69
AS #9	6.36	5.92	8.00	2.08
AS #10	6.82	7.18	4.00	-3.18
AS #11	6.55	6.44	8.00	1.56
AS #12	6.20	5.49	8.00	2.51
AS #13	5.73	4.20	2.00	-2.20
AS #14	6.65	6.71	10.00	3.29

The residual from the values above is +1.45. This shows that there may well have been a very positive effect on the performance of AS level student because of the use of a thinking skills approach to teaching and learning.

However, the AS level exam is new and not the same as the old A level modular exam that the ALIS data was intended to predict, although, due to the normal distribution of candidates' performance, it would be expected that the same general pattern would be adhered to even if the general regression equation did show slight variations. The *exact* regression equation for the new AS specification will only be available once the same amount of information has been analysed as has been available in the old A level scheme.

To investigate how the two might vary, the performance of modular A level physics students was compared with linear (end of course) A level physics students. The regression equation for linear physics is given by:

$$\text{Predicted grade} = (\text{Average GCSE grade} \times 3.09) - 14.45$$

which is not a great deal different when compared with the modular regression equation. To demonstrate the similarity, the table below shows how the modular course and the end of course physics A level exams compare.

Table 7.18 Comparison between modular and linear courses at AS level, based on ALES data

Grade	Modular	Linear	Residual
A*	10.44 (A)	10.27 (A)	0.17
A	7.67 (B/C)	7.18 (B/C)	0.49
B	4.94 (D)	4.09 (D)	0.85
C	2.21 (E)	1 (N/U)	1.21

The results are similar in terms of grades, but the regression equations do show that it is easier to obtain a pass at modular physics A level than it is to obtain a pass at linear (end of course) A level. Also, it is more likely that a student will pass with a grade C at GCSE if that student does the modular course. The number of students included in the sample for the modular research data was 8000 students for the modular exam and 1500 students for the linear exam.

The next chapter will summarise the conclusions that can be drawn from the results obtained from the research and will also deal with improvements which may be implemented to try and improve any subsequent work surrounding the area.

Chapter Eight

Summary of Findings and Implications for Further Research:

This study has clearly demonstrated the potential that thinking skills approaches have in helping students learn difficult concepts in physics.

The preliminary research established that certain areas of the physics syllabus at GCSE and A level were deemed to be more difficult than others based on their content and the amount of demand placed on the working memory. In particular, those areas that were highly symbolic and sub-micro in nature were deemed to be most difficult; easier topics were generally more 'macroscopic' in nature.

In addition it was shown, very conclusively, that there is a sharp decrease in the amount of information that can be effectively processed by the working memory. At 9 digits string length, the degree of similarity fell from virtually 100% similarity to 0.81% similarity (N=189). This demonstrates the importance of not overloading students with too much information at one time. Small 'chunks' of alphanumeric material can be handled much more efficiently than large chunks in a short space of time.

The preliminary research emphasised some important aspects of metacognitive learning. Students who applied metacognitive techniques, such as certainty of response indices, provided very reliable evidence for the argument that how certain a student is that he or she has provided a correct response is directly proportional to their performance in any given test (correlation = 0.500, $p < 0.05$). This would indicate that less academic achievers

generally know that they are lower ability students as opposed to being ignorant of their learning and it would also suggest that highly academic students 'know' that they are high achievers.

Mathematics scores in exams correlated highly with performance in physics exams at GCSE (correlation = 0.535, $p < 0.05$) and also at AS level (correlation = 0.603, $p < 0.05$). The mathematics score correlated highly with tests in all areas of physics, such as earth and space, as well as other areas such as energy and electricity and magnetism. This would indicate that performance is not 'domain specific' and that a good mathematician is usually a good physicist, irrespective of the syllabus area. Preliminary research also showed that performance in one area of physics correlated highly with performance in another area (correlation = 0.795, $p < 0.05$ for earth and space versus electricity and magnetism). The same relationship was observed between how well students performed in physics tests as opposed to practical and investigative skills that was referred to as process score (correlation = 0.803, $p < 0.05$). The same pattern was also observed between physics exam scores and the extent to which vocabulary was successfully understood and applied by students (correlation = 0.605, $p < 0.05$).

As a pre-cursor to the main research results, the GCSE and AS level students were tested via CASE materials to diagnose their current stage of learning. Both sets of data agreed with national figures in that the distribution of Piagetian levels was in line with what would be expected nationally for a similar secondary institution.

As for the main results, those GCSE students who were exposed to the 7 week thinking skills package did show an improvement in examination performance when compared with the control group, for the year 10 cohort. The internal examinations results for the year 10 cohort showed a net improvement of 7.7% once discriminant analysis techniques had accounted for previous differences in the groups' examination performance. The most important results for year 10 and year 11 students were the t-test and effect size data. These showed that despite there being very little difference between the groups based on their performance in the easier F-tier papers, the experimental groups significantly out-performed the control groups in the H-tier papers. The t-test results showed that those students who had been given the thinking skills treatment performed significantly better than the control group. The effect sizes for years 10 and 11 in the H-tier papers were 0.84 and 0.76 respectively. The effect size between the two year groups based on their performance in the 'electricity and magnetism' test was 1.33 in favour of the experimental group. This finding would tend to indicate that even a 7-week period thinking skills course is sufficient to improve understanding of difficult concepts in physics at secondary school level.

For year 11 students at GCSE, the internal examinations results showed improvements of 3% and 9% respectively in favour of the thinking skills group over a longer period of 15 months, which involved a much more detailed exposure of the thinking skills available. Discriminant analysis showed no initial differences in the average exam scores of the students in the control and experimental groups prior to this experiment.

For the year 11 students who had most recently completed their GCSE course and received their results, Yellis results showed that the experimental group had obtained a Yellis score of +0.31 and the control group had achieved a Yellis score of +0.13. This indicates that, compared with the other students in the country sitting physics at GCSE, both groups had received a positive residual, with the experimental group achieving a higher Yellis residual because of the thinking skills package.

The AS level results were analysed via the available ALIS data based on the Yellis results from the previous year. The regression equation showed an average positive residual of +1.4. Despite not being able to have a control group at AS level due to timetabling constraints, the positive ALIS residual does show that value has been added and that students are performing above expectation based on Yellis results. For this cohort, there has been improvement at GCSE and AS level and this would be because of the thinking skills package that has been delivered. AS level students were keen to emphasise their positive feelings about the strategies during subsequent interviews and questionnaires.

Having completed the research and analysed the qualitative responses of the students, it became apparent that there were three ways in which the thinking skills materials were useful. They were useful in improving examination performance, motivation and confidence of the students. In a final plenary session some students commented that introducing them to the materials and to metacognitive strategies improved their exam scores in comparison to previous years. As a result of this, some students had greater

confidence in their 'learning power' that manifested itself through an increase in motivation. Some students felt more confident because they could see the thinking skills ideas as being a structure that underpinned the course. For these students it was not so much the materials that improved their performance but the philosophy of reflective, metacognitive learning that allowed them to monitor their own performance. These students were of the idea that although the materials produced were of some use, the more universal aspect of being taught how to learn effectively transcended the materials and so their progress could not just be attributed to the specific materials and skills used.

In terms of improvements, there are a number of areas where the research could be bettered. Being a teacher in such a small institution, there has been a problem with the number of students that have been included in the research. Statistically, larger numbers would have been more favourable although I am pleased with what my results show. Similarly, external validity could have been improved by having another school's students taking part in the thinking skills programme. Unfortunately, it was not possible to obtain access to a school where the same syllabus was being taught at GCSE and no schools in the vicinity of my school were studying the same AS level course.

As thinking skills can be taught to younger children, from the age of about 8 or 9, it might have been advantageous to have started teaching thinking skills materials at an earlier stage and it would have been interesting to see how this might have further enhanced learning. This was not possible in the timescale that I was given but it might well become part of a larger, more detailed research venture.

In terms of further research, it would be interesting to apply a similar thinking skills package to students in other schools and see the effect it has there. Once this has been completed then a broader view of the effect of a thinking skills curriculum can be seen. The CASE project has received much praise because of the improvements that it has made to secondary education but there is also space in the curriculum for non-CASE materials that are equally accessible.

Educationally, publishers are becoming much more aware of the use of thinking skills strategies in the physics classroom and materials are now being produced as part of publishers' textbooks, schemes of work, teachers' guides and dedicated websites. By doing this, thinking skills strategies can be immediately available to teaching staff who are often overburdened with other teaching initiatives and constant changes to policy. There is currently a huge interest in this area and it can only be a positive step forward in my opinion to include thinking skills materials in text books, copymaster files and teachers' guides. With such a large number of text books being sold it could be possible to administer further research to determine whether the thinking skills materials present were having any effect on GCSE results or value added residuals. This is obviously a massive undertaking, but the government's current interest in critical thinking initiatives could lead to this being a part of the educational agenda. The new QCA document entitled 'Excellence in Schools' (2000), produced by the DfEE, makes reference to the use of thinking skills strategies in the new QCA units for GCSE. As has previously been the case, the theory is included but there are no actual specific thinking skills materials

provided. This has to be the next stage involving the government, PGCE departments in universities, publishing companies and newly qualified teachers. Students would also welcome a curriculum that gives them access to the correct methods of learning including revision techniques and good examination preparation. Currently, too little time is spent on proper examination preparation based on students' needs and this leaves many students unfamiliar with how to approach examination material.

Newton (1995) has commented that there are often gaps in textbooks where too much knowledge is assumed and students are left to bridge the gap between the author's comments and the actual end point of successful knowledge. This very important area of too much knowledge being assumed needs to be addressed in my opinion. Mayer (1989) also makes comment about this incompleteness in the explanation of science and how it leave gaps that are too difficult to bridge if a significant 'feeling of knowing' is to be obtained. Expert knowledge often assumes what novices do not know, which may have enormous detrimental effects on learning, understanding and motivation. If a greater appreciation of students' cognitive and metacognitive needs were employed in the writing of science textbooks then thinking skills strategies could be applied alongside material that is much easier to understand. Authors of textbooks need to realise that the reason why, for example, an image appears to be upside down can be explained by stating (Newton, 2000) 'the rays of light cross over as they travel in straight lines through the pinhole.' Texts that do this are far more effective at teaching physics material than ones that do not explicitly explain why the image appears the way that it does. It has been stated that textbooks can be improved by providing clarified, elaborated missing

information and by making the connections between them far more explicit (Newton, 2000). Only when the pre-requisite knowledge is included in a clear form can thinking skills be used effectively to enhance, augment and maximise learning. This might increase the 'text density' of textbooks, but I am certainly in favour of having too much good information than too little truncated and, subsequently, inadequate information. This is an issue that encompasses the whole of the governmental, publishing and teaching community.

The way that students are questioned has also been mentioned as being an important factor to consider in the area of effective teaching and learning. Questions are often asked by teachers and textbooks that focus on purely factual information and recall (Newton, 1997). Questioning techniques need to be employed that ascertain where students are in their learning so that they can be stimulated or made to think and consider other possible answers. Some thinking skills techniques, both CASE and non-CASE materials, try to do this, but they need to be made available to all teachers and students and to be used at the appropriate stage of their learning. Using a non 'means-end' approach in questioning (Sweller, 1994) could allow students to exhibit their own capabilities when answering questions rather than giving them a 'means-end' task where the goal is specified. Questions like these will also move away from the more comfortable 'low demand' style questions where students reach the 'answer' and then the questioning and learning episode ends. Often, increasing the demand of questions, provided the question is within the student's capabilities, will help stimulate learning and understanding.

Other areas to consider when trying to develop strategies for the benefit of students' learning include (Newton, 2000) ways of checking, altering and updating prior knowledge, ways of reducing processing load and ways of engaging unconscious processes in the endeavour.

The other area of interest would involve the brain and how the brain handles information. Over recent months there has been great excitement in the discovery that the left parietal lobe region of the brain has been highly significant in the learning of mathematics. Further neurological work involving working memory and specific areas of the brain could be very exciting in terms of the way that the brain handles material on a cognitive and metacognitive plane. There is still an enormous volume of work to be carried out in this field and it may be many years before we understand the role played by metacognition on a neural level.

References

- Anderson, A. (1999). The cocktail (highball) problem. *Physics Education* Vol. 34 No. 2 pp. 76-79.
- Anderson, C.W. (1987). Strategic teaching in science *Strategic Teaching and Learning: Cognitive Instruction in the Content Areas*, pp. 73-91.
- Anderson, J.R. (1983). *The Architecture of Cognition (2nd edition)*. Harvard University Press. Cambridge: Massachussetts.
- Atkinson, R.C. and Shiffrin, M.J. (1968). Human Memory: A proposed system and its control processes. In K.W. Spence and J.T. Spence (Eds) *The Psychology of Learning and Motivation, Volume 2*. Academic Press: London.
- Atkinson, R.C. and Shiffrin, M.J. (1971). The control of short-term memory. *Scientific American*, 224, 82-90.
- Ausubel, D. (1968). *Educational Psychology, A Cognitive View*. Holt, Rinehart and Winston, Inc. New York.
- Baddeley and Hitch (1974). Working memory. In G.H. Bower (Ed.). *The Psychology of learning and motivation* Vol. 8, pp. 47-90. Academic Press. New York.
- Baddeley, A.D. (1986). *Working Memory*. Oxford University Press (Clarendon). London
- Baddeley, A.D. (1990). *Human Memory: Theory and practice*. Lawrence Erlbaum Associates Ltd. Hove.
- Baddeley, A.D. (1995). Memory. In C.C. French and A.A. Colman (Eds) *Cognitive Psychology*. Longman: London.
- Bower, G.H. and Springston, F. (1970). Pauses as recoding points in letter series. *Journal of Experimental Psychology*, 83, 421-430.
- Bransford, J. Brown, A.L. et al. (1999). *How People Learn*. National Academy Press: Washington D.C.
- Brown, A. (1975). The Development of Memory: Knowing, Knowing about Knowing and Knowing how to Know. In *Advances in Child Development and Behaviour* (Vol. 10). National Academic Press. New York.
- Brown, D.E. (1994). Facilitating Conceptual Change Using Analogies and Explanatory Models. *International Journal of Science Education* 16: 201-214.

- Brown, K. (1998). *Education, Culture and Critical Thinking*. Ashgate Publishing Ltd. Aldershot. UK.
- Butterworth, B (1999). *The Mathematical Brain*. Macmillan. London
- Buzan, T. (2000). *The Mind Map Book*. BBC books. London.
- Chi, M.T.H. and Glaser, R. (1981). Categorization and representation of physics problems by experts and novices *Cognitive Science* 5: 121: 152.
- Coolican, H. (1994). *Research methods and statistics in psychology (2nd Edn.)*. Hodder and Stoughton. London.
- Cowan, N. (2001). The Magic Number Four in Short-Term Memory: A Reconsideration of Mental Storage Capacity. *Behavioural and Brain Science* 24 (1).
- Craft, A. (2001). The multiple intelligences debate *Teaching Thinking* 3, pp. 12-15.
- Driver, R. et al. (1995). *Young People's Images of Science*. OUP. Bristol, PA.
- Delazer et al. (1996). A dissociation of number meanings. *Cognitive Neuropsychology*, 14, 613-36.
- Dufresne et al. (1997). Solving physics problems with multiple representations. *Physics Teacher* 35 pp 270-5.
- Egan, K. (1983). *Education and Psychology*. Methuen. London.
- Ellis, N and Hennelly, R. (1980). A bilingual word-length effect: implications for intelligence testing and the relative ease of mental calculation in English and Welsh. *British Journal of Psychology* 71, pp. 43-51.
- Emerick, L.J. (1992). Academic underachievement among the gifted: Students' perceptions of factors that reverse the pattern. *Gifted Children Quarterly*, Vol.36 pps. 140-146.
- Ericsson, K. Krampe, R. Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review* 100, pp. 363-406.
- Eysenck, M.W. and Keane, M.J. (1990). *Cognitive Psychology: A Student's Handbook (3rd Edition)*. Psychology Press, Hove UK.
- Eysenck, M.W. (2000). *Psychology: A student's handbook*. Psychology Press Ltd. Hove, UK.

- Fitz-Gibbon, C.T. and Morris, L.L. (1987). *How to Analyse Data*. Sage Publications. London.
- Flavell, J. H. (1973). Metacognitive aspects of problem solving *The Nature of Intelligence*. Lawrence Erlbaum Associates. Hillsdale, N.J.
- Gardner, H. (1993). *The Unschooled Mind: How Children Think and How Schools Should Teach*. Basic Books. New York.
- Gardner, H. (1983). *Frames of Mind: The theory of multiple intelligences*. Basic Books. New York.
- Georghiades, P. (2000). Beyond conceptual change learning in science education: focusing on transfer, durability and metacognition. *Educational Research* 42, pp. 119-139.
- Gill, P.N.G. (1999). The physics/maths problem again. *Physics Education* Vol. 34, No. 2, pp 83-87.
- Glaserfeld, E. (1989). Cognition, construction of knowledge and teaching. *Synthese* 80 pp. 121-40.
- Glaserfeld, E. (1992). A constructivist's view of learning and teaching *Proc. Int. Workshop on Research in Physics Education: Theoretical Issues and Empirical Studies, Bremen, Germany*. IPN Kiel, Germany.
- Gross, R. (2001). *Psychology, The Science of Mind and Behaviour (4th Edition)*. Hodder and Stoughton. London: UK.
- Gagne, R., Briggs, L. and Wager, W. (1992). *Principles of Instructional Design (4th Ed.)*. HBJ College Publishers. Fort Worth, Texas.
- Guzzetti, B.J. (1990). Effects of Textual and Instructional Manipulations on Concept Acquisition. *Reading Psychology* 11: 49-62.
- Hameed, H., Hackling, M.W. and Garnett, P.J. (1993). Facilitating Conceptual Change in Chemical Equilibrium. *International Journal of Science Education* 20: 393-412.
- Haberlandt, K. (1997). *Cognitive Psychology*. Allyn and Bacon: Boston.
- Halford, G.S. (1993). *Children's Understanding: The Development of Mental Models*. Erlbaum. Hillsdale, NJ.
- Handy, C. (1994). *The empty raincoat: making sense of the future*. Hutchinson.

- Hasan, S. Bagayoko, D. Kelley, E.L. (1999). Misconceptions and the certainty of response index in *Physics Education*. Vol 34, No.5, pps. 294-299.
- Hulme, C. and Mackenzie, S. (1992). *Working Memory and Severe Learning Difficulties*. Lawrence Erlbaum Associates Ltd. Hove.
- Hynd, C., McWhorter, J.Y., Phares, V.L. and Suttles, C.W. (1994). The Role of Instructional Variables in Conceptual Change. *Journal of Research in Science Teaching* 31: 933-946.
- James, W. (1890). *Principles of psychology*. Holt. New York.
- Johnstone, A. H., El-Banna, H. (1986). Capacities, demands and processes – a predictive model for science education in *Education in Chemistry* Vol.23, No. 3, pp 80-85.
- Johnstone, A.H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning* (1991) 7 pp. 75-83.
- Johnstone, A.H., Hogg, W.R., Ziane, Z. (1993). A working memory model applied to physics problem solving. *International Journal of Science Education* Vol. 7, No. 6, pp.663-672.
- Jensen, E. (1995). *Brain-based learning and Teaching* (Turning Point). The Brainstore Inc. Anglo-American book company. Carmarthen.
- Kibble, B (1999). How do you approach a physics problem? *Physics Education* 34 pp 16-18.
- Lonning, R.A. (1993). Effect of Co-operative Learning Strategies on Student Verbal Interactions and Achievement During Conceptual Change Instruction in 10th Grade General Science. *Journal of Research in Science Education* 30: 1087-1101.
- Luria, A.R. (1968). *The Mind of a Mnemonist*. Basic Books: New York.
- Mayer, R.E. (1989). Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology* 81: 240-246.
- Mestre, J.P. (2001). Implications of research on learning for the education of prospective science and physics teachers. *Physics Education* Vol. 36 No. 1 pps.44-49.
- Miller, G.A. (1956). The magical number seven, plus or minus two. Some limits on our capacity to process information. *Psychological Review* 63: 81-87.
- Miller, G.A. and Selfridge, J.A. (1950). Verbal context and the recall of meaningful material. *American Journal of Psychology*, 63, 176-185.

- Mehl, M. (1985). The cognitive difficulties of first year physics students at the University of the Western Cape and various compensatory programmes. PhD thesis, University of Cape Town.
- Moll, L.C. (1990). *Vygotsky and Education*. Cambridge University Press. Cambridge, UK.
- Naveh-Benjamin, M. and Ayres, T.J. (1986). Digit span, reading rate, and linguistic relativity. *Quarterly Journal of Experimental Psychology* 38A, pp. 739-751.
- Newton, D.P. (1995). Support for Understanding: Discourse Which Aids the Construction of a Functional Mental Model of Causal Situations. *Research in Science and Technological Education* No. 13 pp. 109-122.
- Newton, D.P. (1997). Teachers' Questioning for Understanding in Science. *British Journal of Curriculum and Assessment* No. 8 pp. 28-32.
- Newton, D.P. (2000). *Teaching for Understanding*. Falmer Press. London.
- Nussbaum, J. and Novick, S. (1981). Brainstorming in the classroom to invent a model: a case study. *School Science Review* 62, 771-778.
- Patton, M.Q. (1980). *Qualitative evaluation methods*. Sage. London.
- Piaget, J., Inhelder, B. (1969). *The Psychology of the Child*. Basic Books. New York.
- Remond-Besuchet, C. et al. (1998). Selective preservation of exceptional arithmetical knowledge in a demented patient *Mathematical Cognition* 5.
- Raw, A. (1998). A thinking skills approach to A-level physics questions. *School Science Review* pp 95-104.
- Reason, J.T. and Rowan, J. (Eds.) (1981). *Human Enquiry: A sourcebook in new paradigm research*. Wiley. Chichester.
- Resnick, L. (1983). Mathematics and science learning: A new conception *Science* 220, pp. 477-478.
- Saxana, A.B. (1992). An Attempt to Remove Misconceptions Related to Electricity. *International Journal of Education* 14: 157-162.
- Schweickert, R. and Boruff, B. (1986) Short-term memory capacity: magic number or magic spell? *Journal of Experimental Psychology: Learning, Memory and Cognition* 12 pp. 419 – 25.

- Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence *Journal of Experimental Child Psychology* 49, pp. 31-57.
- Schraw, G. (1997). Helping Gifted Students Develop Metacognitive Awareness. *Roeper Review* Vol. 20, No. 1. pps. 4 – 8.
- Scruggs et al. (1986). Effective mnemonic strategies for gifted learners. *Journal of Education for the Gifted*, No. 9, pp. 105-121.
- Scott, P. Asoko, H. Driver, R. (1991). Teaching for conceptual change: a review of strategies. *Research in Physics Learning: Theoretical Issues and Empirical Studies*. IPN, pp. 310-329. Bremen.
- Shayer, M. and Adey, P. (1981). *Towards a Science of Science Teaching*. Heinemann Educational. Oxford.
- Shayer, M., Adey, P., Yates, C. (1995). ‘*Thinking Science*’, the materials of the CASE project. Thomas Nelson and Sons ltd. Walton-on-Thames, Surrey.
- Smith, A., Gardner, H. (1998). *Accelerated learning in practice* (NEP).
- Standing, L., Bond, B., Smith, P., Isley, C. (1980) Is the immediate memory span determined by subvocalisation rate? *British Journal of Psychology* 71, pp 525 – 539.
- Strike, K. and Posner, G. (1985). A conceptual change view of learning and understanding *Cognitive Structure and Conceptual Change*. Academic Press, pp. 211-231. London.
- Sutton, C. (1992). *Words, Science and Learning*. Open University Press. Buckingham.
- Sweller, J. (1994). Cognitive Load Theory, Learning Difficulty and Instructional Design. *Learning and Instruction* 4: 295-312.
- Tao, P.K. (2001). Confronting students with multiple solutions to physics problems. *Physics Education* Vol. 36, No. 2, pp 135-139.
- Thomas, G. and Durant, J. (1987). Why should we promote the public understanding of science? *Scientific literary papers* No. 1, pp.1-14.
- Vosniadou, S. (1992). Knowledge Acquisition and Conceptual Change. *Applied Psychology: An International Review* 41: 347-357.
- Vosniadou, S. (1994). Capturing and Modeling the Process of Conceptual Change. *Learning and Instruction* 4: 45-69.

Vygotsky, L. (1962). *Thought and Language*. M.I.T. Press. Cambridge, Massachussetts.

Watts, D.M. and Alsop, S.J. (1997). A feeling for learning: modelling affective learning in school science *Curriculum Journal* 8, pp. 351-365.

West, T.G. (1991). *In the mind's eye: visual thinkers, gifted people with learning difficulties, computer images and the ironies of creativity*. Prometheus. Buffalo, New York.

Appendices

- Appendix 1: Questionnaire used to determine the easiest and most difficult areas of the GCSE physics syllabus.
- Appendix 2: Questionnaire used to determine the easiest and most difficult areas of the AS-level physics syllabus.
- Appendix 3: Questionnaire used to determine the easiest and most difficult areas of the legacy A-level physics syllabus.
- Appendix 4: Questionnaire used to determine the areas that are believed to be easiest and most difficult in other subjects, based on the opinions of teachers.
- Appendix 5: Questionnaire used to determine the areas that are believed to be easiest and most difficult in GCSE physics, based on the opinions of physics teachers.
- Appendix 6: Instructions read to students prior to and during working memory data collection episode.
- Appendix 7: Questionnaire used to determine the knowledge and understanding of physics-specific terms, with associated CRI values.
- Appendix 8: Questionnaire used to determine the understanding of vocabulary that can be understood via different physics-specific and mundane definitions.
- Appendix 9: Materials used to determine the extent to which the different multiple intelligences were developed for students involved in the research.
- Appendix 10: Questionnaire to determine opinions concerning Raw's ideas about why students under-perform under examination conditions.
- Appendix 11: Metacognition 'bubble sheets' used during the GCSE and AS level research period.
- Appendix 12: Explanatory sheet for wrestling maths with associated questions.
- Appendix 13: Science reasoning test (SRT) style test.
- Appendix 14: Macro-micro-symbolic style questions.
- Appendix 15: Introductory concept mapping materials.

- Appendix 16: Concept map work produced by student for legacy A level physics syllabus.
- Appendix 17: Examples of P.M.I. style questions used at GCSE and AS level.
- Appendix 18: Introductory pole-bridging material.
- Appendix 19: Introductory key words material.
- Appendix 20: Introductory thinking graphs materials.
- Appendix 21: Introductory mnemonics materials used at GCSE and AS level.
- Appendix 22: Introductory VAKi materials used at GCSE.
- Appendix 23: Introductory KWL material used at GCSE and AS level.
- Appendix 24: Metacognitive question grids and associated metacognitive material.
- Appendix 25: Exemplar materials produced by students to assist research.
- Appendix 26: Multi-model store representation of human memory.
- Appendix 27: Alternative theories concerning conceptual change learning.
- Appendix 28: Raw data for year 10 groups involved in research with corresponding t-test and effect size statistics.
- Appendix 29: Raw data for year 11 groups involved in research with corresponding t-test and effect size statistics.
- Appendix 30: Table needed for t-test calculations.
- Appendix 31: Standardisation proforma used during year 10 teaching period.

Appendix 1

Questionnaire used to determine the easiest and most difficult areas of the GCSE physics syllabus.

1. Listed below are 36 areas that you may have studied as part of your GCSE Physics course. Please write a number next to each one to indicate how easy or difficult you found each area.

The scale to use is:

- 1- really easy
- 2- easy
- 3- not too bad
- 4- quite difficult
- 5- difficult
- 6- very difficult

- The wiring and working of a 13A plug _____
- Ohm's Law (including graphs and calculations) _____
- I-V graphs (for diode, bulb and resistor) _____
- Logic (logic gates, truth tables etc.) _____
- Simple d.c. circuits (involving cell, bulbs and switches) _____
- Transistors in circuits (base, emitter, collector) _____
- The National Grid (including the transformer equation) _____
- Magnets (attraction and repulsion) _____
- Electromagnets (use of. Factors which affect strength of) _____
- Momentum (equation, conservation of momentum) _____
- Moment of a Force (balanced see-saws etc.) _____
- Friction (surfaces in contact, affect on velocity) _____
- Centripetal Force (Circular motion, satellites, etc.) _____
- Boyle's Law (pressure in gases) _____
- Conduction, Convection and Radiation (thermal transfer) _____
- Renewable Resources (solar, tidal, geothermal) _____
- Efficiency (calculating how efficient machines are) _____
- Power and Energy (energy used per second) _____
- Day, Night, Year, Seasons (why they happen) _____
- The Solar System (Sun and planets) _____
- Big Bang Theory (origins of the Universe) _____
- Life Cycle of Stars (birth, life and death of a star) _____
- Transverse and Longitudinal Waves (nature of light and sound) _____
- The Electromagnetic Spectrum (radio, micro, gamma, etc.) _____
- The Eye and Ear (structure and function) _____

- Lenses and mirrors (types) _____
 - Nature of Images (real, virtual, magnified, inverted, etc.) _____
 - The wave equation ($v=f\lambda$) _____
 - Ultrasound (sound above 20kHz. Uses of) _____
 - Seismic Waves (P and S waves. Earthquakes) _____
 - Reflection of light (from surfaces and mirrors) _____
 - Refraction of light (air to glass, etc.) _____
 - Total Internal Reflection (critical angle, etc.) _____
 - Diffraction (spreading of waves at a boundary/obstacle) _____
 - Radioactivity and decay (half-life, background radiation) _____
 - Nuclear Fission (thermal neutrons, nuclear power stations) _____
2. Pick one of the topics that you found most difficult and explain why you found it so difficult in the box below:

The most difficult topic was: _____

because: _____

3. Pick one of the topics that you found the easiest and explain why you found it so easy in the box below:

The easiest topic was: _____

because: _____

Appendix 2

Questionnaire used to determine the easiest and most difficult areas of the AS-level physics syllabus.

Year 12 Interview... Physics AS Modules 1,2 and 3.

1. What is your name? Kate Ashfield
2. What were your GCSE grades for a) Maths C
- b) Physics B?
3. How difficult were the following areas of Module 1?

Area of Module 1	Difficulty (see scale)
Rutherford's model of the atom	2
Hadrons, Baryons, Leptons, etc.	2
Feynman Diagrams	3
Conservation Laws (B,L,S,C)	3
Photoelectric effect	4
Electron diffraction	3 4
Refraction and TIR	5
Atomic Spectra	3
Photon Energy ($E = hf$, $E = hc/\lambda$)	4

- Scale: 1 = really easy
- 2 = easy
- 3 = not too difficult, but not easy
- 4 = difficult
- 5 = very difficult or impossible

1. Pick one of the areas that you found easiest and state why it was easier than the others:

Rutherford's Scattering
Mainly because the information needs to be recalled and learnt not understood and applied.

2. Pick one of the areas that you found most difficult and state why it was so difficult:

Refraction and TIR also Electron diffraction due to amount of maths and equations needed to solve questions asked.

3. Please complete the following table concerning thinking skills techniques that you have heard of:

Technique	Heard of	Used	Useful
Concept maps	✓	✓	✓
Reinforcement	✓	✓	✓
PMI	✓		
KWL		✓	

VAKi	✓	✓	
------	---	---	--

Pole Bridging	✓		
Question writing	✓		
Metacognition	✓	✓	✓
CRI tests	✓	✓	✓

1. Explain how you learn and revise for physics exams. In particular, mention:

- How you revise
- How long you revise for each time you sit down
- How often you revise each week
- Any strategies you use that are 'physics specific'.

a) read + answer questions

b) 30 min

c) 3 times a week

d) No

2. What aspects of the teaching that took place suited or did not suit your preferred learning style?

Practicle work and diagrams

Mathematicle talk - does not work.

Appendix 3

Questionnaire used to determine the easiest and most difficult areas of the legacy A-level physics syllabus.

1. Below is a list of the topics that you have studied as part of the PHO1 course for 'A' level Physics.

Please indicate, by using the scale, how difficult you found each area.

Scale:

1 - really easy
2- easy
3- not too bad
4- quite difficult
5- difficult
6- very difficult

- scalars and vectors _____
- Equilibrium of rigid bodies _____
- Turning effects _____
- Displacement, speed, velocity, acceleration _____
- SUVAT equations _____
- Independence of Horizontal and Vertical Motion _____
- Momentum _____
- Conservation of linear momentum _____
- Newton's laws of motion _____
- Uniform motion in a circle _____
- Work and Energy _____
- Conservation of Energy _____
- Power and Efficiency _____
- Structure of solids _____
- Bulk Properties of Solids _____
- The Young Modulus _____
- Charge, Current, Voltage and Resistance _____
- Energy and Power in d.c. circuits _____
- Series and Parallel Resistor circuits _____
- Resistivity _____
- Ohm's Law _____
- Current/Voltage Characteristics _____
- Kirchhoff's 1st Law _____
- Potential Divider _____
- Electromotive Force and Internal Resistance _____

2. From the list above, choose one of the areas that you found very difficult and explain why it seemed very difficult to you.

Because:

- An easy topic was _____.

Because _____

Appendix 4

Questionnaire used to determine the areas that are believed to be easiest and most difficult in other subjects, based on the opinions of teachers.

Doctorate in Education Research

Questionnaire #4

Professional Opinions concerning Difficult Concepts (General)

Introduction:

Please could you answer the following questions concerning difficult concepts in your subject / teaching area. If there is any other information that you could add that the questionnaire fails to highlight, then feel free.

Thank you for your time.

This questionnaire should not take any longer than 15 minutes.

Name JOANNA BRUCE

Subject Specialism GERMAN

1. Which area(s) (*) of your subject do students usually find the 'easiest' in terms of the demand that it places on their intellect?

(*) an area may be a whole module or a small part of a module.

Students find listening skills (and to a lesser extent reading skills) easier than other areas.

2. What do you think it is about this area that makes it 'easy' compared to other areas?

In listening, pupils are not required to produce the foreign language, only to comprehend it. Their passive vocabulary is far greater than their active vocabulary. Also, because very little reading or writing is required, pupils are not "put off" by large chunks of text which can, at first, seem overwhelming. Cognates also make guessing easy. In reading, again, pupils manage quite well because their passive vocabulary is at work.

3. Which area of your subject do your students find particularly 'difficult' in terms of the demands it places on their intellect?

Pupils find written tasks in the foreign language very difficult.

4. What do you think it is about this area that makes it 'difficult' compared to other areas of your subject?

Pupils quickly become demotivated because they feel that it takes a disproportionately long time to produce a short piece of writing. They get no-where fast! And because languages are not linear, pupils feel that they have just mastered one rule only to find that the next "layer" of learning means that rule cannot always be applied. Dictionaries often

do not help because pupils have difficulty in using them efficiently. Also, pupils often feel that what they are asked to write is not interesting or not relevant to them (of course you can deal with this last point by providing interesting tasks). Unfortunately, like it or not, we have to stick to the exam syllabus to a high degree.

Thanks very much for your time.

→ Mike O'Brien

Doctorate in Education Research

Questionnaire #4

Professional Opinions concerning Difficult Concepts (General)

Introduction:

Please could you answer the following questions concerning difficult concepts in your subject / teaching area. If there is any other information that you could add that the questionnaire fails to highlight, then feel free.

Thank you for your time.

This questionnaire should not take any longer than 15 minutes.

Name A.J. Slater

Subject Specialism Russian (Languages)

1. Which area(s) (*) of your subject do students usually find the 'easiest' in terms of the demand that it places on their intellect?

(*) an area may be a whole module or a small part of a module.

Listening comprehension work.

2. What do you think it is about this area that makes it 'easy' compared to other areas?

It is essentially a passive skill, in which general intelligence, common sense and clear thinking can be as useful - or almost - as proficiency in Russian.

3. Which area of your subject do your students find particularly 'difficult' in terms of the demands it places on their intellect?

1. Compound Verbs of motion (at GCSE and A-level)
2. (at GCSE) telling the time!

4. What do you think it is about this area that makes it 'difficult' compared to other areas of your subject?

1. The concept does not feature in the English grammatical system, so there is no direct area of comparison. Also, it is not possible to lay down clear-cut rules, since some usages are idiomatic.

2. Telling the time in Russian is a grammatical nightmare, entailing cardinal numbers, ordinal numbers, preposition requiring oblique cases... The contrast with the simplicity of the English system is more than many can bear!

Ag. J. Dett
20.3.2012

Thanks very much for your time.

Appendix 5

Questionnaire used to determine the areas that are believed to be easiest and most difficult in GCSE physics, based on the opinions of physics teachers.

Doctorate in Education Research

Questionnaire #4

Professional Opinions concerning Difficult Concepts (General)

Introduction:

Please could you answer the following questions concerning difficult concepts in your subject / teaching area. If there is any other information that you could add that the questionnaire fails to highlight, then feel free.

Thank you for your time.

This questionnaire should not take any longer than 15 minutes.

Name Fred Welsh

Subject Specialism Physics / Maths

1. Which area(s) (*) of your subject do students usually find the 'easiest' in terms of the demand that it places on their intellect?

(*) an area may be a whole module or a small part of a module.

Forces / light / E+Space.

2. What do you think it is about this area that makes it 'easy' compared to other areas?

Forces + light : Much 'concrete' things
that students can see / observe / feel and
use the 'mini' concepts that become
grasped to use a foundation to
see & understand 'the whole'.

3. Which area of your subject do your students find particularly 'difficult' in terms of the demands it places on their intellect?

Electricity / Electronics / Atomic Structure
Emission.

4. What do you think it is about this area that makes it 'difficult' compared to other areas of your subject?

Very abstract topics - they need to
visualize what's happening 'below the
surface' or at least accept the current
model - not always easy!

This highlights very well the Macro/
Micro conflict and for me the movement
from graspable to more difficult, even
impossible for some, concepts.

Thanks very much for your time.

Appendix 6

Instructions read to students prior to and during working memory data collection episode.

Working Memory Instructions.

(To be read out to class before administering working memory material)

[Hand out paper, establish silence]

You are going to hear a list of numbers that you are to try and remember. There are twelve sets of numbers in total. The first sets of numbers consist of four digits. The number of digits present in each set will increase until there are 12 digits for you to listen to. After each set of numbers has been read out, you will be asked to pick up your pen and write down the numbers that you have just heard. Please do not pick up your pen and start to write until you are asked to do so. After each set of numbers has been read out, you will be asked to put your pen back down and listen for the next set of numbers. There will be a 20 second gap between each set of numbers. Try to recall and write down the numbers in exactly the same order as you heard them.

[Prepare class]

Here come the numbers... [five second pause]

Set 1 : 3...8...6...9 write [20 second gap] put your pen down

Set 2: 4...9...5...3...1 write [20 second gap] put your pen down

Set 3: 8...2...6...7...9...5 write [20 second gap] put your pen down

Set 4: 4...1...0...9...0...6...7 write [20 second gap] put your pen down

Set 5: 8...1...9...3...6...2...4 write [20 second gap] put your pen down

Set 6: 5...4...7...7...9...0...2...3 write [20 second gap] put your pen down

Set 7: 6...1...1...4...1...9...7 write [20 second gap] put your pen down

Set 8: 3...8...9...9...2...4...0...6 write [20 second gap] put your pen down

Set 9: 4...7...5...6...9...7...5...2...8 write [20 second gap] put you pen down

Set 10: 3...8...3...3...6...6...4...2...7 write [20 second gap] put your pen down

Set 11: 7...4...1...9...6...8...7...3...6...8 write [20 second gap] put your pen down

Set 12: 5...7...9...6...4...2...1...4...8...0...3...9 write [20 second gap] put your pen down

Appendix 7

Questionnaire used to determine the knowledge and understanding of physics-specific terms, with associated CRI values.

Circle the correct answer to the meaning of the words below. If you think the correct response is 'a' then circle 'a'. In the circle next to each question, write a number from 1 to 5 based on this scale:

1. – I have no idea and this is a total guess.
2. – I have a vague idea, but I could be wrong.
3. – I think I am correct, but I am not totally sure.
4. – I am fairly certain.
5. – I am totally convinced that I am correct.

1. What does the word 'current' mean in physics:

- a) A force
- b) A movement of electric charge
- c) The pressure pushing charge around the circuit
- d) The size of the cell voltage?

2. Which of the following steps voltage up and down:

- a) A transducer
- b) A transformer
- c) A transistor
- d) A transferor?

3. Which of the following words means 'returns to its original form when forces are removed':

- a) Plastic
- b) Deformed
- c) Molecule
- d) Elastic?

4. Which word below means 'a body not wanting to change its current state of rest or motion':

- a) Inertia
- b) Resistance
- c) Voltage

d) Friction?

5. What is 'mass x velocity' called:

- a) Moment
- b) Momentum
- c) Inertia
- d) Acceleration?



6. What is acceleration:

- a) A change in shape
- b) A change in pressure
- c) A change in distance
- d) A change in speed?



7. What does 'renewable' mean:

- a) Cannot be replaced
- b) Can be replaced
- c) Can be recycled
- d) Cannot be recycled?



8. Which law concerns springs:

- a) Ohm's law
- b) Law of Conservation of Momentum
- c) Hooke's Law
- d) Murphy's Law?



9. What is the pull of gravity on our bodies called:

- a) Weight
- b) Pressure
- c) Mass
- d) Volume?



10. What is the unit of Energy:

- a) Watt
- b) Joule
- c) Kilogram
- d) Pascal?



Appendix 8

Questionnaire used to determine the understanding of vocabulary that can be understood via different physics-specific and mundane definitions.

The following words have meanings in common, everyday usage, but they also have meaning in Physics. See how well you can fill in the two columns, one of which contains the everyday meaning and the other one that contains the physics meaning. The first one has been done for you:

Term:	Everyday usage	Physics usage
1. Current	happening at the moment	the flow of electric charge
2. Conductor		
3. Concentration		
4. Power		
5. Induction		
6. Moment		
7. Conservation		

8. Resistance

9. Charge

10. Mass

11. Friction

12. Solution

13. Wave

14. Work

15. Pressure

16. Cell

17. Potential

18. Volume

Appendix 9

Materials used to determine the extent to which the different multiple intelligences were developed for students involved in the research.

ACCELERATED LEARNING IN PRACTICE



M U L T I P L E I N T E L L I G E N C E

Please complete the following questionnaire by assigning a numerical value to each of the statements which you consider represents you. If you agree that the statement very strongly represents you assign a 5. If the statement does not represent you assign a 0. Use the numbers 5 - 0 to grade each statement.

On the following page, transfer the outcomes to the seven (plus one) intelligences listing and then complete the sectioned wheel.

1. I always do things one step at a time
2. I recognise and can name different types of birds, trees or plants
3. I can visualise remembered or constructed scenes easily
4. I have a well developed vocabulary and am expressive with it
5. I enjoy and value taking written notes
6. I have a good sense of balance and enjoy physical movement
7. I keep or like pets or other domestic animals
8. I know myself well and understand why I behave as I do
9. I enjoy community activities and social events
10. I learn well from talks, lectures and listening to others

11. I am skilful in working with objects
12. When listening to music I experience changes in mood
13. I enjoy puzzles and logical problems
14. I like to think out loud, to talk through problems, ask questions
15. I remember things like telephone numbers by rhythmic repetition
16. Charts, diagrams, visual displays are important for my learning
17. I am sensitive to the moods and feelings of those around me
18. I enjoy being outdoors and am comfortable there
19. I learn best when I have to get up and do it for myself
20. I order and prioritise and sometimes work off a to-do list

21. I need to see something in it for me before I want to learn something
22. I like to think through problems whilst doing something such as walking or running
23. I am able to explain topics which are difficult and make them clear
24. I have a good sense of direction
25. I have a natural ability to sort out arguments between friends
26. I can remember pieces of music easily
27. I can take things apart and re-assemble them easily
28. I enjoy games involving other people
29. I like privacy and quiet for working and thinking
30. I can pick out individual instruments in complex musical pieces

31. I can discern patterns and relationships between experiences or things
32. In teams I co-operate and build on the ideas of others
33. I am interested in psychology and human motivation
34. I am observant and will often see things others miss
35. I get restless easily
36. I enjoy working or learning independently of others
37. I enjoy making music
38. I am angered by environmental neglect or obvious pollution
39. I have a facility with numbers and mathematical problems
40. I am an independent thinker and I know my own mind

Multiple Intelligences: scoring

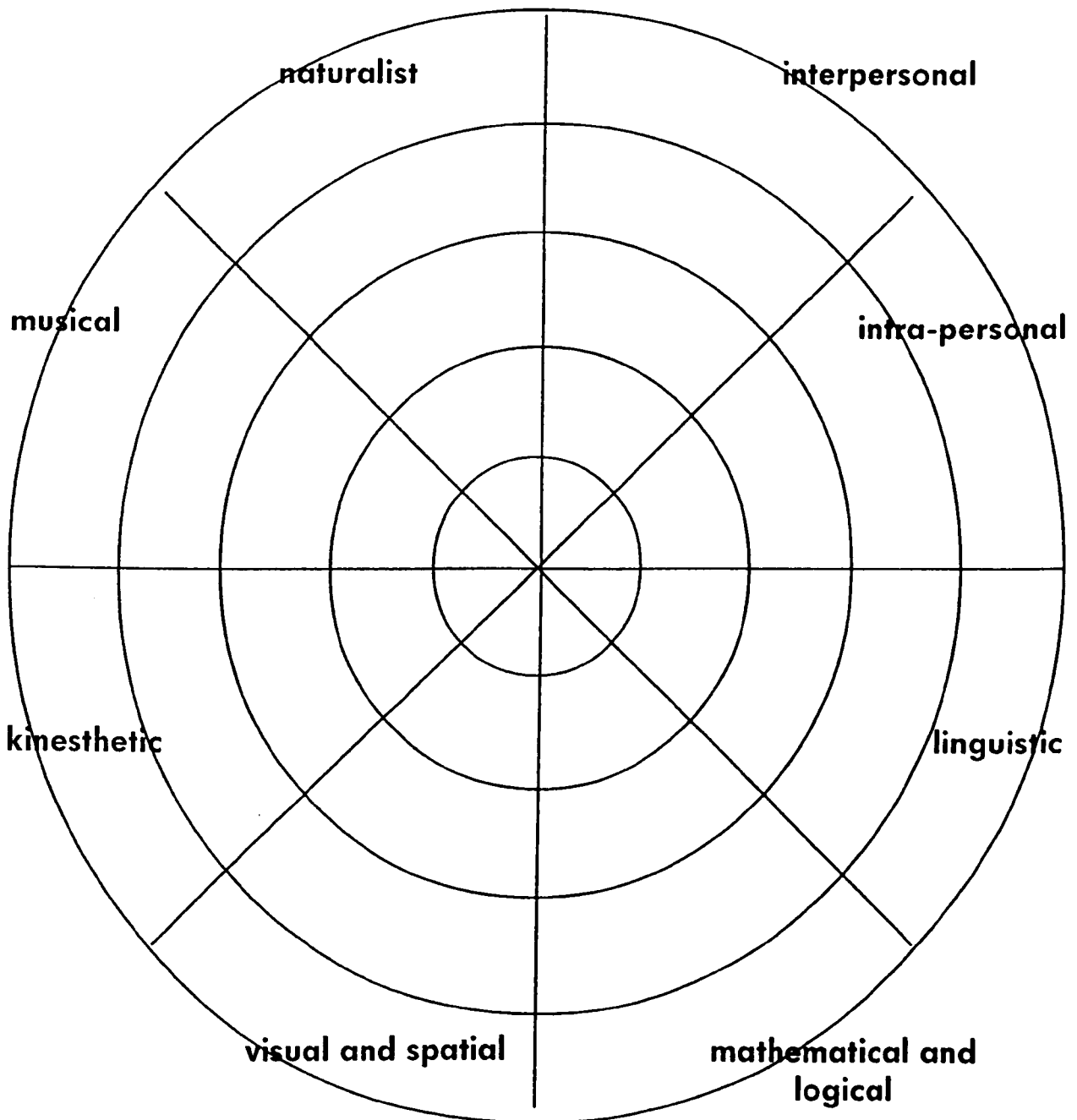


Intelligence	Statements	Total score
interpersonal scoring	9, 17, 25, 28, 32
intrapersonal scoring	8, 21, 29, 36, 40
linguistic scoring	4, 5, 10, 14, 23,
mathematical and logical scoring	1, 13, 20, 31, 39
visual and spatial scoring	3, 16, 24, 34, 27
kinesthetic scoring	6, 11, 19, 22, 35,
musical scoring	12, 15, 26, 30, 37
naturalist scoring	2, 7, 18, 33, 38

Multiple Intelligences wheel



By taking the numerical score against each intelligence from the questionnaire, plotting it on the wheel and shading each segment you will get a visual representation of your balance of intelligences according to Howard Gardner's theory. Shade to the approximate position within each segment - eg., if you scored 16 shade to a position just into the 15 - 20 space.



Appendix 10

Questionnaire to determine opinions concerning Raw's ideas about why students under-perform under examination conditions.

Raw's Criteria.

When you attempt physics problems or physics examination questions, there will be times when you experience problems. A teacher called Any Raw has identified 11 areas where he believes students experience difficulties. Use the values 1 to 5 below to show what you think about these statements and how they apply **to you**. Your teacher will explain what each statement means in more detail as you are filling in the questionnaire, so don't worry if you don't understand what the statement means at first.

Use these values to fill in the grid:

Response to statement	Value relating to response
I totally agree that this statement is relevant to me	1
I partially agree that this statement is relevant to me	2
I am unsure of this statement's relevance to me	3
I believe that this statement has little relevance to me	4
I believe that this statement has no relevance to me to me	5

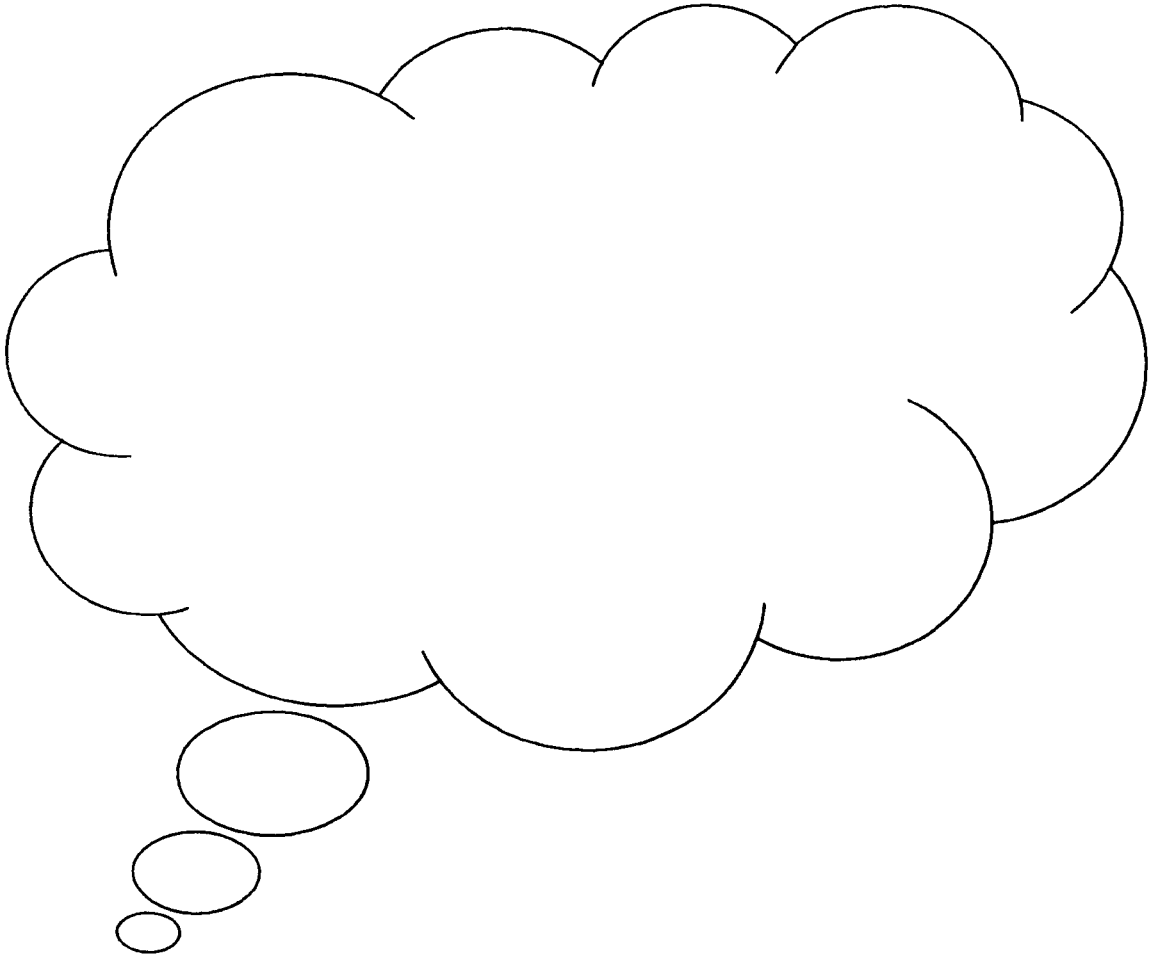
Statements:

1. Not reading a problem carefully _____
2. Impulsivity _____
3. Blocking _____
4. Poor visualisation of the problem _____
5. Unplanned and unsystematic approach _____
6. Monitoring _____
7. Motivation _____
8. Lack of precision in work _____
9. Difficulty with two sources of information _____
10. Difficulty in spotting implied information _____
11. Difficulty in explaining things clearly. _____

Appendix 11

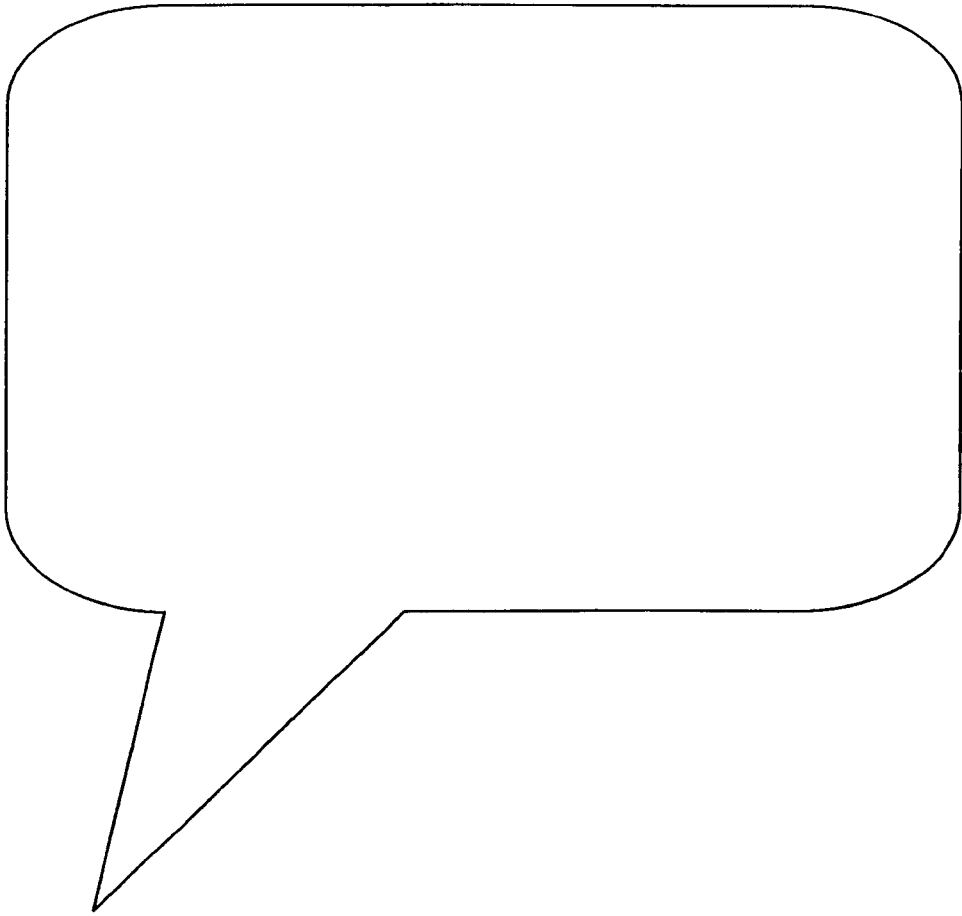
Metacognition 'bubble sheets' used during the GCSE and AS level research period.

Metacognition sheet: my ideas.



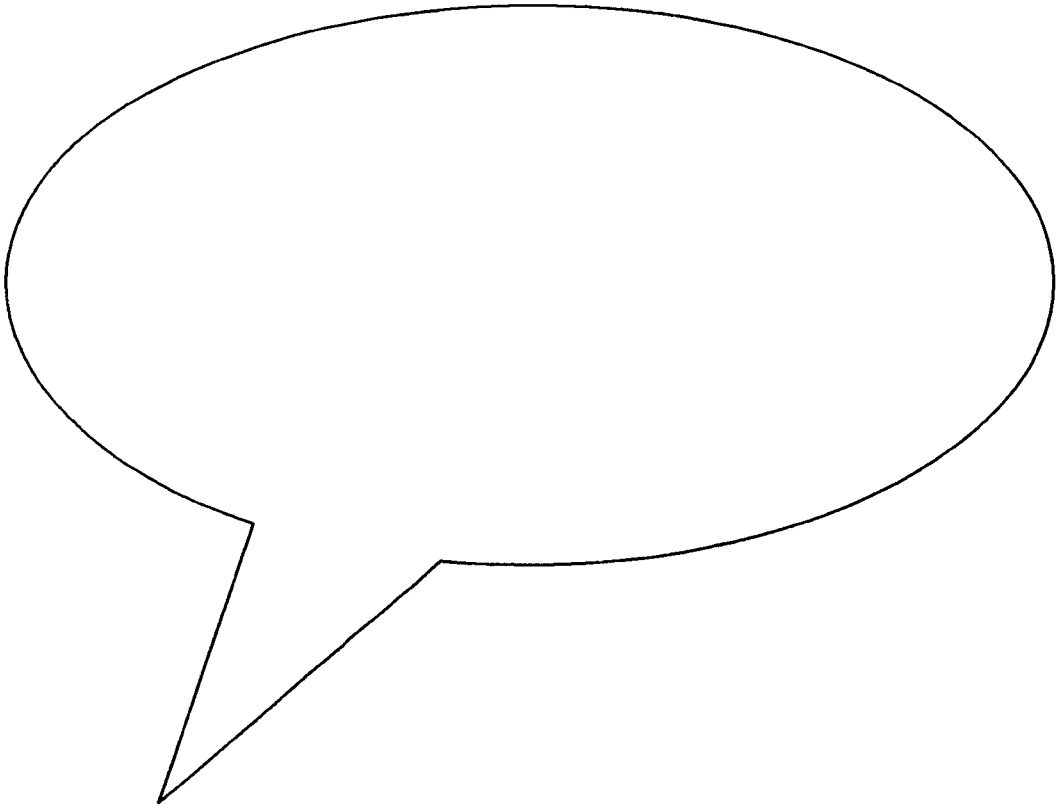
**"What are my ideas concerning this
topic?"**

Metacognition sheet: my problems.



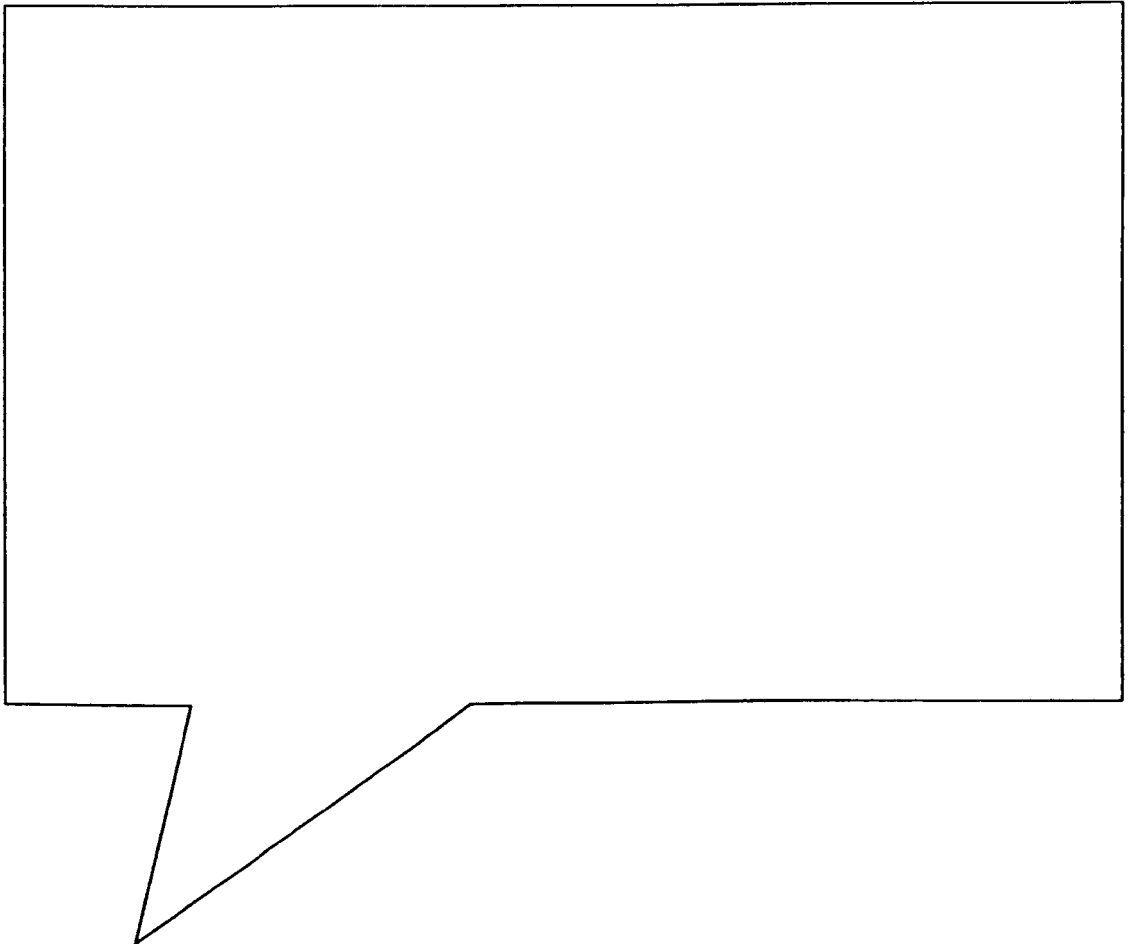
**"What are my problems concerning
this topic?"**

Metacognition sheet: my questions.



**"What are my questions concerning
this topic?"**

Metacognition sheet: my knowledge.

A large, empty speech bubble shape with a rectangular body and a pointed tail at the bottom left, intended for a student to write their knowledge about a topic.

"This is what I know about this topic!"

Appendix 12

Explanatory sheet for wrestling maths with associated questions.

Wrestling Maths

Seeing as most students are fascinated by WWF wrestling, we shall use it to explain how maths works...get ready...

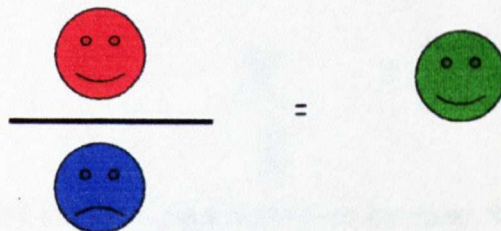
Imagine that the three terms in an equation are three wrestlers...



As you can see, there is one wrestler on one side and two wrestlers on the other side of the 'equal to' sign. The blue and green wrestlers are multiplying together.

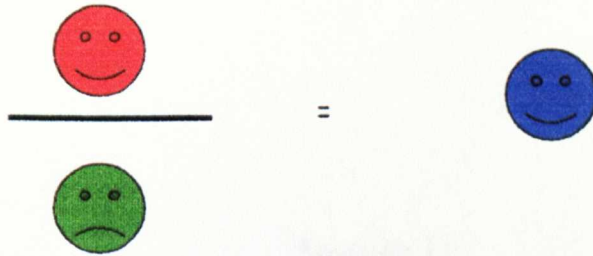
What happens when the blue wrestler goes across the 'equal to' sign?

The answer is, the red wrestler wrestles him to the ground:



Notice the sad look on the blue wrestler's face as he is wrestled to the ground by the red wrestler.

The same thing happens when the green wrestler goes across 'the equal' to sign as shown on the next page.



The simple rule is... the red wrestler always wins!!

You can do the same thing with the letters, or terms, in an equation. For example... suppose we have an equation like the one below:

$$V = I \times R$$

The same thing happens, but with the terms. If I want to get the 'R' by itself then we take the 'I' across the 'equal to' sign the equation becomes...

$$\frac{V}{I} = R$$

And... we also get another equation when we take the 'R' across...

$$\frac{V}{R} = I$$

This time, the letter 'V' is the wrestler that is top dog.

Appendix 13

Science reasoning test (SRT) style test.

TASK II

SCIENCE REASONING TASKS

NAME

TODAY'S DATE

BOY OR GIRL

CLASS

SCHOOL

DATE OF BIRTH

day month year

VOLUME AND HEAVINESS

1.



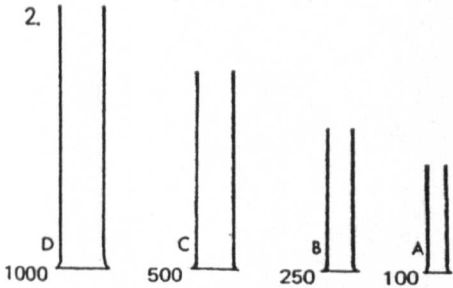
(tick the best answer)

A has more

less

the same amount of water compared with X.

2.



Do these cylinders all have the same amount of water?

YES

NO

If you answered "NO"

write down which has most

(A/B/C/D)

3.a) The pop-corns have less

more

the same amount of maize, compared with the grains.

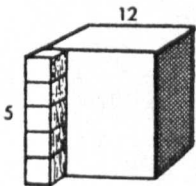
b) The pop-corns weigh more

less

the same compared with the grains.

4.

(show your working here)



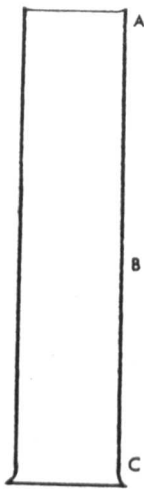
What is the volume of this plasticine block, in cubic centimetres?

Your answer

Correct answer

5. How much water will spill over when the plasticine is all under water?

6.



You see that water spills over when the block is lowered to A.

If it is lowered to B instead, will more

less

the same amount of water spill over ?

If it is lowered to C instead, will less

more

the same amount of water spill over ?

7.



What will the new volume-reading be?

.....

8.

If the plasticine is made into a ball, will the level be the same



higher

lower ?

9.

If the plasticine is made into a cylinder, will the level be the same



higher

lower ?

10.

If the metal block is lowered in, will more

less

the same amount of water spill over ?

Why?

.....

.....

-

13. a)

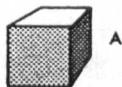


How do you think Archimedes measured the old and the new crowns' volumes to compare them, using a measuring cylinder?

- b) Archimedes then weighed the two crowns and found that the new, bigger crown weighed more than the old one. Nevertheless he said that the new crown had some lighter metal in it.

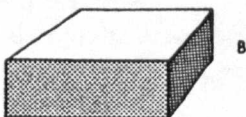
How do you think he worked it out?

14.



Both blocks are made of the same brass.

A weighs 60 grams, and its volume is 15cm^3 .



B weighs 160 grams.

What is its volume? cm^3 .

How did you work out your answer?

TASK II

VOLUME AND HEAVINESS

Michael Shayer
Research Fellow, Chelsea College
University of London

Introduction

This Task* is one of a series developed by the team 'Concepts in Secondary Maths & Science' at Chelsea College, University of London in the period 1973/78 in order to investigate the relationship between the optimum Piagetian level at which a pupil can function and the understanding of Science which he or she can achieve.

This Task is based on most of the chapters in J. Piaget and B. Inhelder, 'The Child's Construction of Quantities', Routledge, London, 1974.

It works on the principle that initially, for the child, there is a global concept of 'size' in which mass, weight, volume and density are not differentiated clearly from each other. The first of these to 'crystallise out' is mass — conservation of substance (Stage 2A). A little later (Stage 2A/2B) weight is conserved, and a global, intuitive concept of density is differentiated from weight. Then volume is conserved, and differentiated from mass and weight (Stage 2B/3A). Finally, with volume and weight consistently differentiated, comes an analytical concept of density as a weight/volume ratio (3A). At about the same time the child sees that whether something floats is governed by its weight compared with the weight of the same volume of water.

The Task is hierarchically constructed, with the first 3 items testing the Intuitive/Middle Concrete distinction (1/2A). The scoring rules are based on a 2/3rd success rate as a criterion for being at a stage. The whole Task takes about 50 minutes. A practice-run without pupils is recommended.

Equipment

Glass trough
1000 cm³ measuring cylinder
500 cm³ measuring cylinder
250 cm³ measuring cylinder
100 cm³ measuring cylinder
Some grains of maize † (for popping)
4 'popcorns' made from such maize
17 x 1 cm wooden cubes
5 x 4 x 3 cm brass or iron block
2 lumps of plasticine 5 x 4 x 3 cm
Perspex 10 x 10 x 10 cm box
Two feet of stout thread
250 cm³ squat beaker
100 cm³ beaker, watch glass to cover
Burner, tripod, gauze

† For maize please read corn if you are a North American.

*For information on the use, development, statistics, etc. of this Task see the General Guide.

Administration

All through this Task please remember it is your ability to communicate with your class that we want to make the most of. Please rephrase and restate any question in your own words to ensure that the pupils understand clearly what it is they are being asked.

Before the class comes in, put enough cooking oil into a 100 cm³ beaker just to cover the bottom. Set it on a gauze on a tripod. While the pupils complete the details at the top of their question sheets, start to heat the oil. When hot, show them that you are adding unpopped maize grains, cover with a watch glass, and turn the heat down low. The maize will pop in 3 or 4 minutes. If this is difficult have some popcorn prepared beforehand.

- Qu. 1 A is the 100 cm³ measuring cylinder. X is the 250 cm³ beaker. Fill A at the tap. Emphasise that it is full. Pour into X. Refill A. Put A and X alongside each other so they can be seen. Put the questions.
- Qu.2 Fill A at the tap. Pour into D. Refill A. Pour into C. Refill A. Pour into B. Refill A. Put all 4 together in line so they can be seen. Put the questions.
- Qu.3 By now the maize should be popping in the beaker. Remove some of the popcorn. Emphasise that 'popcorn' is made straight from maize grains. Show them both. Let them drop on the bench so that they can hear the 'solidness' of the grains. Put the 2 sets of questions.
- Qu. 4 Make sure that the top of your plasticine block is flat. Show them that 5 1cm cubes just measures the height, and then fit 12 cubes so they just cover the top of the block. Count them in front of the class. Put the question. Afterwards give the correct answer of 60 cm³ (needed for next questions).
- Qu. 5 Fill the 1000 cm³ cylinder to overflowing point and stand in the trough. Show them the plasticine behind or in front of the cylinder just below the water surface (not in the water). Put the question (emphasise that it is the volume of water that is wanted).
- Qu. 6 Use the thread to hang the plasticine block lengthways, by using it like a cheese cutter. Lower it into the water, showing the water overflowing. Remove the plasticine and refill to overflowing point. Put the question (emphasise that it is the volume of water that is wanted).
- Qu. 7 Pour water out of the cylinder until 500 cm³ remain. Say: "If I lower the plasticine into the water until it is just under the surface, what will the water level in the cylinder be?"
- Qu. 8 Actually roll the plasticine to make a sphere so they can see you do it. Put the question (as compared with Qu. 7).
- Qu. 9 Roll the plasticine to a long thin sausage shape. Put the question (again compared with Qu. 7).
- Qu. 10 Pass the brass block together with the other prepared plasticine block (if only one plasticine block was available, reform the 5 x 4 x 3 cm cube from the sausage shape in Qu. 9) round the class so they can 'weigh' both in their hands. Refill the 1000 cm³ cylinder to the top. Put the questions.
- Qu. 11 Squeeze the plasticine so it makes a disc about 10 centimetres in diameter. Have the trough half full of water. Ask the first question. Then lower it in (it sinks). Take it out. Remove about 1/3rd of it. Squeeze this 1/3 into an even thinner disc. Put the second question, but do not demonstrate. Then take off a very small piece, so that squeezed as thin as will still hold together it is about 1 cm across. Show it to them and ask the third question.
- Qu.12 Show the 10 x 10 x 10 cm box. Say it is so light they can forget about its own weight. Emphasise that the second box in the question is just like it, but TWICE as tall. Repeat the information in question a). Show the box again and put first question. Emphasise that it is very important to show the working or reasoning being used – no credit otherwise – when they have finished show the box again and read question b).

- Qu.13 This is a version of Archimedes and the King. Tell them that the King had a new crown made, which was supposed to be bigger and better than his old one. However, when it arrived the King suspected that his goldsmith had stolen some of the gold and mixed in some lighter metal (copper?) to make the weight up again. The King asked Archimedes to find out if the new crown was pure gold. Archimedes then set about measuring separately the volume of each crown, and the weight of each crown. Put the questions. If pupils ask, say he made a measuring cylinder large enough to put a crown in.
- Qu. 14 Explain that A and B are both made of the same brass, but the illustrations are not the same scale, so they cannot get the answer by looking at them. Put the question. Again, as in 12, they must show or explain how they got their answer.

Assessment

Score each result as "1" for adequate, and "0" for inadequate and record on the class assessment sheet. Treat each answer only for the information it gives at the level specified for the question (see Summary of Answers and top of Assessment Sheet). Thus if it is a "3A" question as in 12, ignore ingenious replies at the 2B level. Similarly a higher level response to a "2B" question still only gains credit at the 2B level.

Summary of Answers

- | | |
|---|---------|
| 1. Same | (2A) |
| 2. YES | (2A) |
| 3a. Same | (2A) |
| 3b. Same | (2B) |
| 4. 60 cm ³ (but ignore in marking) | — |
| 5. 60 cm ³ (allow wrong units) | (2B) |
| 6. Same, Same (must have both for mark) | (2B) |
| 7. 560 | (2B) |
| 8. Same | (2B) |
| 9. Same | (2B) |
| 10. Same, plus an answer showing understanding that the metal and plasticine blocks are the same size. (Must have both for mark). | (2B/3A) |
| 11. a. Ignore answer as children may have to guess.
b & c. must both be NO for mark. | (2B) |
| 12. All this question must be correct for a mark
a. Sink, plus either a calculation or an explanation comparing volumes and weights etc.

b. Float, plus either a calculation or an explanation comparing volumes and weights etc. | (3A) |

- 13a. Either by putting crowns in cylinders to see how much the level went up, or by measuring the amount of water spilled from a full bath on immersing the crown. (2B/3A)
- 13b. Allow anything showing understanding of volume to weight ratios. Or. "For the same volume the metal in the new crown weighs less". (3A)
14. 40 cm³. But an explanation or working must be shown. (3A)

Scoring Procedure

The method of ascribing a level of cognitive development to an individual has been achieved through the use of Rasch scaling, which makes the best use of all of the pupil data and item data in arriving an equal interval scale.

The level of development is expressed directly as a number on a scale. The scale is based on the following ascription of scores to the **beginning** of each of the levels and sub-levels of thinking:

Early concrete	2A	3.0
Mid concrete	2A/2B	4.0
Mature concrete	2B	5.0
Concrete generalisation	2B*	6.0
Early formal	3A	7.0
Mature formal	3A/3B	8.0
Formal generalisation	3B	9.0

For each person, score "1" on the Task Assessment sheet for each item right, and then use the Table below to convert the total item score to a scale value.

Total	Scale
1	2.0
2	2.8
3	3.4
4	3.9
5	4.3
6	4.6
7	5.0
8	5.3
9	5.6
10	6.0
11	6.3
12	6.8
13	7.3
14	8.1
15	>8.1

If you have a computer spread-sheet, you will find it convenient to record your assessment straight into the computer file. Simply type a template copy of the Task Assessment sheet into your spread-sheet, and enter an instruction in the "Total" column to sum the scores in the item columns. If you then type a copy of the Table above outside the Task matrix, you can use it as a LookUp Table which takes the total score as input, and delivers into the Scale column the corresponding scale level.

Generally speaking the standard error on any task is greater near the ends of each task's range - that is, out of a 15 item task, pupils scoring 1, 2, 14, or 15 will not be as reliably assessed as those scoring in the 3 to 13 range. The standard error of Task II is 0.55 over most of the middle range of scores.

Appendix 14

Macro-micro-symbolic style questions.

GCSE Physics Revision Questions.

Question 1: Forces and Materials

- a) How would you show a young child that a spring can behave in an 'elastic' way or in a 'plastic' way.
- b) A spring is stretched so that it goes beyond its elastic limit and will not return to its original shape. Explain what you think is happening to the internal structure of the metal by explaining what is happening to the metal atoms when the spring is being stretched.
- c) A force of 3N produces an extension of 20cm, for a particular spring. Assuming that the spring does not exceed the elastic limit, determine the extension of the spring for the following forces:
 - i) 6N
 - ii) 15N
 - iii) 1.5N
 - iv) 5.4N

Question 2: Balanced and Unbalanced Forces

- a) A fiat Punto is left at the top of a steep hill. The driver releases the hand brake and takes his foot off the brakes. Explain, using your knowledge of forces, what happens next and why.
- b) The brakes in the car are hydraulic brakes which use a liquid, such as water, to apply pressure to the brake pads, causing the car to slow down and stop. Explain what happens to the water molecules in the hydraulic brakes when the driver applies a force to the brake pads.
- c) The force provided from the engine of a car is 4500N and the force of friction on the car is 1500N. If the mass of the car is 1800kg, find the acceleration of the car.

Question 3: Turning Forces

- a) Why might you use a long spanner to untighten a nut rather than a short spanner?
- b) Draw the spanner and show where you would expect to find its 'centre of mass'. What is meant by the 'centre of mass' and explain why we need to use such a thing as 'centre of mass'.
- c) Two boys sit on either side of a seesaw that is 4m long and pivoted at the middle. One boy who has a mass of 75kg sits, on the left side, at 1 metre from the pivot and another boy, who has a mass of 55kg, sits on the right of the seesaw. Draw the set up and calculate where the boy would have to sit on the right side of the seesaw for it to balance.

Question 4: Speed, distance and time.

- a) Put these in order of their speed starting with the fastest: a car, a tortoise, a person walking at normal walking pace, a jet aircraft and a sleeping cat.
- b) A formula one racing car can reach a higher speed than a Renault Clio. Explain why a car must have a maximum speed and explain why the formula one car can reach such a high speed.
- c) A motorcyclist passes lampposts that are 75 metres apart. In a one-minute period the motorcyclist just manages to pass 7 lampposts. What speed is he travelling at?

Question 5: Frictional Forces

- a) Explain when friction can be useful or a nuisance.
- b) Why does friction happen? Why can we walk easily on the pavement but not so easily on an icy road?
- c) A car of mass 2350kg is moving at a speed of 18m/s. The force from the engine is 4500N. What is the size of the frictional force and explain your answer.

Appendix 15

Introductory concept mapping materials.

Developing Thinking Skills

Unit P2: Mind Map

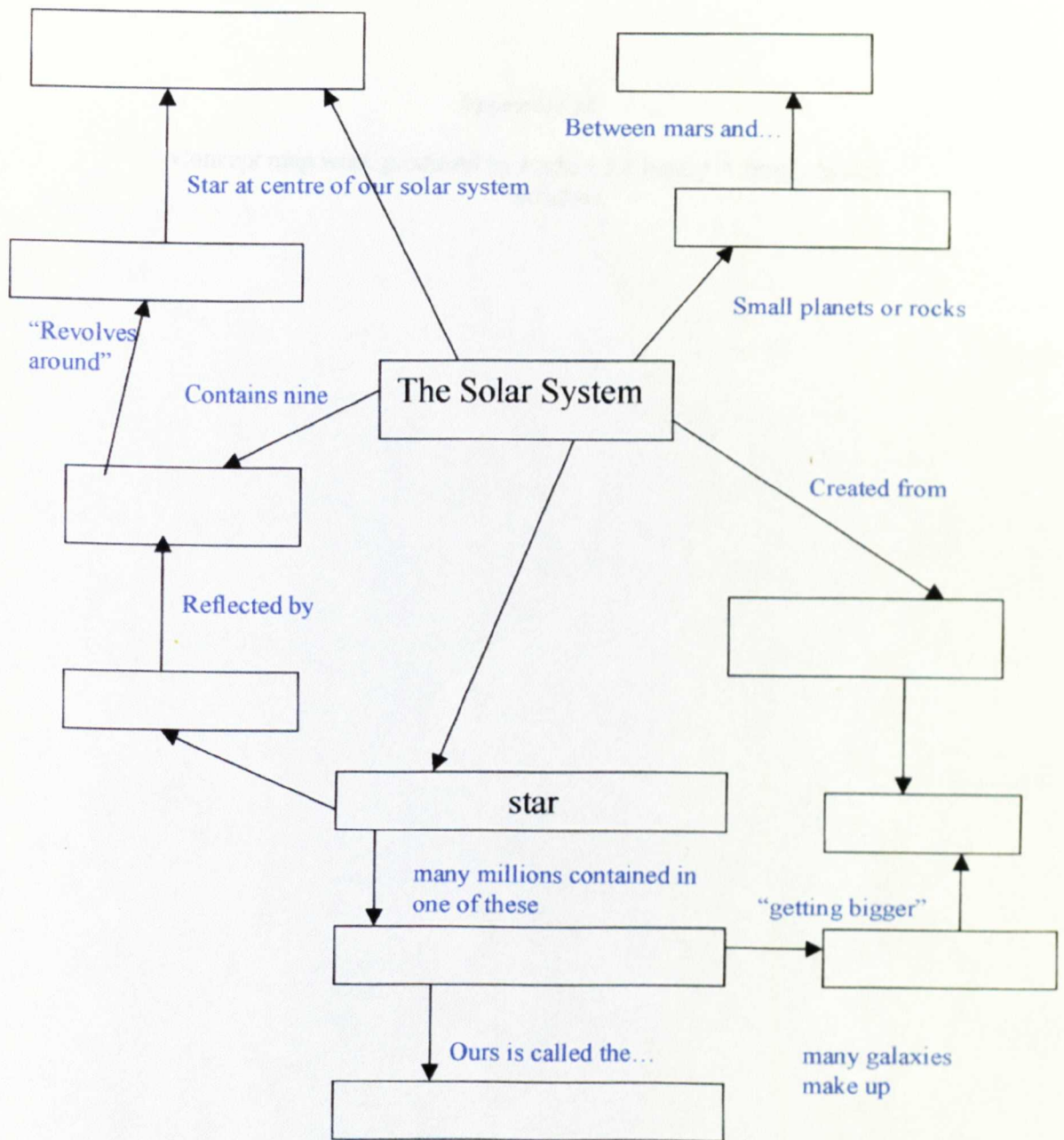
Read the following piece of text about Earth and beyond and use it to fill in the mind map. Some of the words have been included to help you out. Where these words have been taken from the text can be seen because they have been highlighted in yellow.

Our **planet**, Earth, is one of nine planets in the **solar system**. These nine planets all **orbit** (or travel around) the **sun**. The sun is the only star in our solar system. In between **mars** and **Jupiter** there is a group of rocks called **asteroids**.

The sun is one of millions of other stars that make up our **galaxy**. Our galaxy is called the **Milky Way**. Stars give off their own **light** which is why we can see them at night. We see planets near us because they reflect the light from the sun.

The Milky Way is not the only galaxy in our **universe**. There are many millions of galaxies which all contain many millions of stars.

These galaxies are moving at high speed. Many of these galaxies are moving away from us, which means that the universe is **expanding**. Everything that exists, whether we can see it or not, belongs in the universe. What is beyond our universe, we do not know.



Appendix 16

Concept map work produced by student for legacy A level physics syllabus.

Thermodynamics - concept map - (see book for symbols key and units).

#13
#16

$$P_1 V_1 = P_2 V_2$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Derived from Boyle's law

and Charles' law

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Often need this equation as well as others

$$\Delta W = p \Delta V$$

$$pV = nRT$$

work done calculated using

used to calculate anything about ideal gases

Ideal Gas

Pressure produced by an ideal gas

assumption of ideal gas

assumption of ideal gas

assumption of ideal gas

$$\frac{1}{3} \rho \bar{c}^2$$

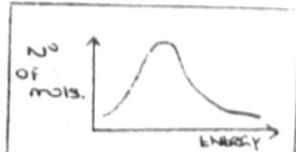
Derived using assumptions of ideal gas, like

all collisions are completely elastic.

collision time is negligible

All internal energy is KE.

For using this equation

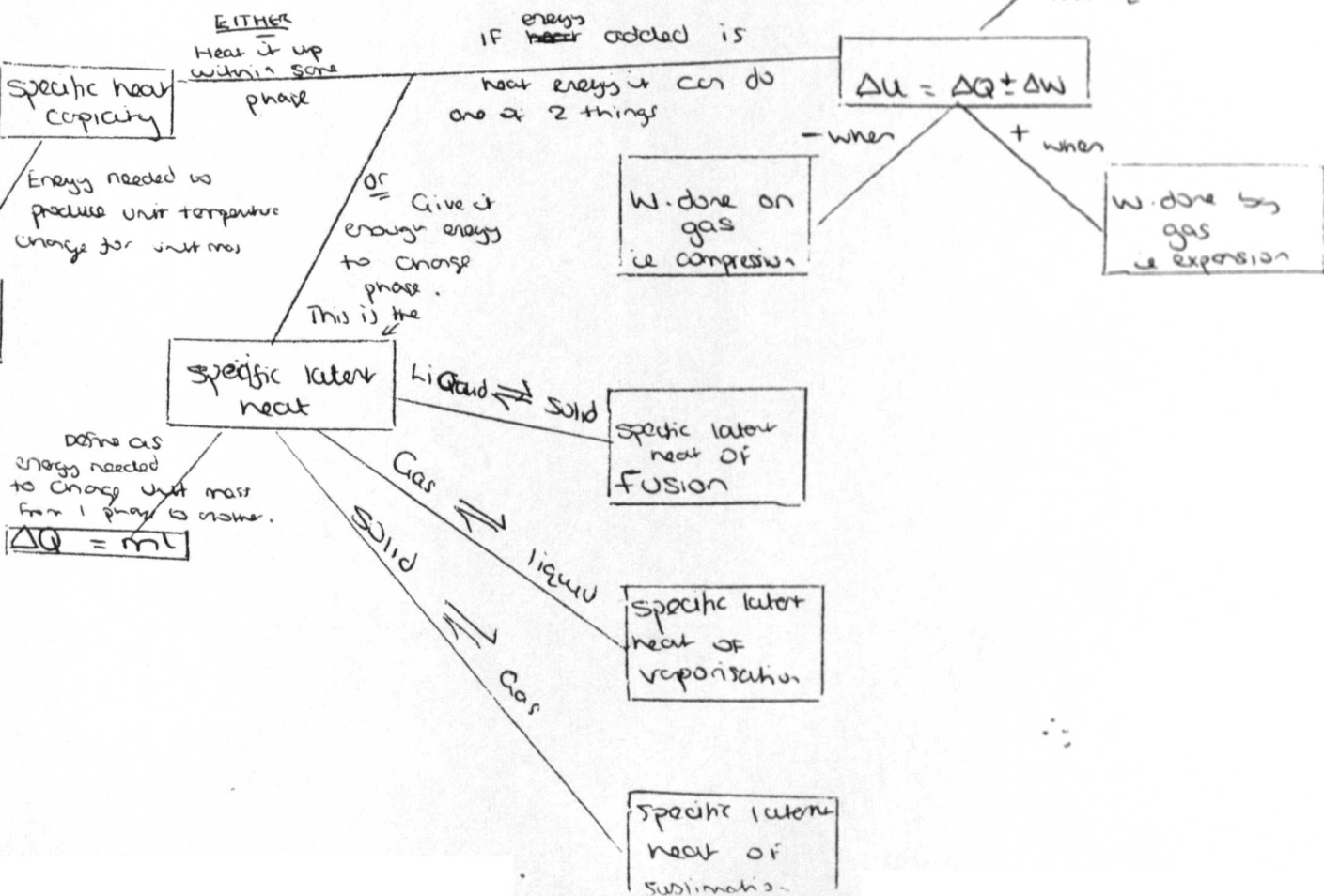


Also small area have much more than average value

Shape like above. No mols have no energy.

Maxwell-Boltzmann distribution

Energy distributed among molecules according to



Appendix 17

Examples of P.M.I. style questions used at GCSE and AS level.

Developing Thinking Skills

Unit P2: P.M.I.

P.M.I. is a thinking skills exercise that stands for 'plus, minus, interesting'. If you are given a statement then you can think of a plus point, a minus point and an interesting point about that statement. For example, suppose you were asked to do a P.M.I. exercise on the following statement:

“ The planets in our solar system should all be closer to the sun”

All you need to do is read the statement and think of the possible answers. Here is an example of one P.M.I. answer:

P: The weather might be warmer if the Earth was nearer the sun.

M: If the planets were closer to the sun then it might be too hot for life to exist on Earth.

I: It would be interesting to see how the length of a year would change if the Earth were closer to the sun.

The great thing about P.M.I. statements is that there isn't one real correct answer. In fact, you might think of even better ones! So, have a go at the statements below. Remember, all you have to do is think of a plus, minus and interesting point for each statement. Try to make them as original as possible and don't worry about what anybody else has written. Your answers are just as important and just as good!

Statements for P.M.I.

1. A day on Earth should last only 10 hours.
2. The same side of the Earth should always face the sun.
3. An eclipse of the sun should occur much more often.
4. The Earth should have more than one moon.
5. Man should not have travelled to the moon.
6. Artificial satellites should not be put into space.
7. The planets in our solar system should be much closer together.
8. Gravity, like electricity in our home, should be able to be switched on and off.

Developing Thinking Skills

P.M.I. Answer Grid

Write Your P.M.I. Statement here:

“ _____ ”

P.	
M.	
I.	

Appendix 18

Introductory pole-bridging material.

Pole Bridging

Pole bridging is a technique that involves you 'talking through' any practical work that you are doing. The idea behind this technique is that you:

- a) speak back to yourself when you are doing your practical so that you can check your method;
- b) allow yourself to be metacognitive (i.e. you can reflect on your procedure to decide if it is the best way to do things);
- c) observe problems when they arise;
- d) correct problems via a metacognitive approach,
- e) see alternative ways concerning why problems might occur;
- f) see alternative ways of carrying out procedures;
- g) discuss whether predictions, when made, have been successful or otherwise.

Today, you are going to build a set of different circuits. Use this technique to help you explain why the ammeter and voltmeter readings vary between circuits. When talking back to yourself, use the words provided in the box below as regularly as possible.

Wire	switch	conductor
Short circuit	bulb	Insulator
Energy	series	resistance
Voltage	parallel	potential divider
Current	potential difference	capacitor
Charge	ions	buzzer

Appendix 19

Introductory key words material.

Developing Thinking Skills

Unit P2: Key Words

For this thinking skills strategy you must read the following passage about space exploration. When you find a science word you must underline it. If the word that you have underlined is also a word that is to do with space then you should also highlight that word with a highlighter pen or circle it.

An example is shown below:

People can travel at a very fast speed, an astronaut can travel many hundreds of metres every second. A satellite has to travel at a very fast speed to stay in orbit around the Earth. Some planets have their own natural satellites called moons. Saturn, for example, has more than ten moons that are held in orbit by the force of gravity.

As you can see, the science words have been underlined and the science and space words have been highlighted as well as being underlined.

Try the same thing with this passage below:

In 1969, humans landed on the moon for the first time. To get to the moon, the spacecraft needed a huge amount of energy to get into space. The energy came from fuel that was burned by the rocket. Neil Armstrong and Buzz Aldrin walked on the moon while a third astronaut, Michael Collins, remained on Apollo 11.

Since 1969 there have been many journeys into space. The Russians launched a space station called Mir that would act as a laboratory where scientists from many countries would perform experiments for over ten years. These experiments were useful because they showed how science worked at zero gravity.

Most recently, the Hubble Space Telescope has been used to look into the furthest reaches of the universe. At first, there was a problem with the mirror on the telescope, but now that has been solved. The Hubble Space Telescope works by collecting light from distant galaxies and analysing it. The light showed that Europa, one of the moons of Jupiter, contains oxygen in its atmosphere. This is the first moon ever to have oxygen found in its atmosphere, which is a good sign because oxygen makes up water and water is needed to sustain life.

Developing Thinking Skills

Key Words answer grid

Key Word	Meaning of Word
Earth	
satellite	
gravity	
orbit	
astronaut	
planet	
star	
asteroid	

Appendix 20

Introductory thinking graphs materials.

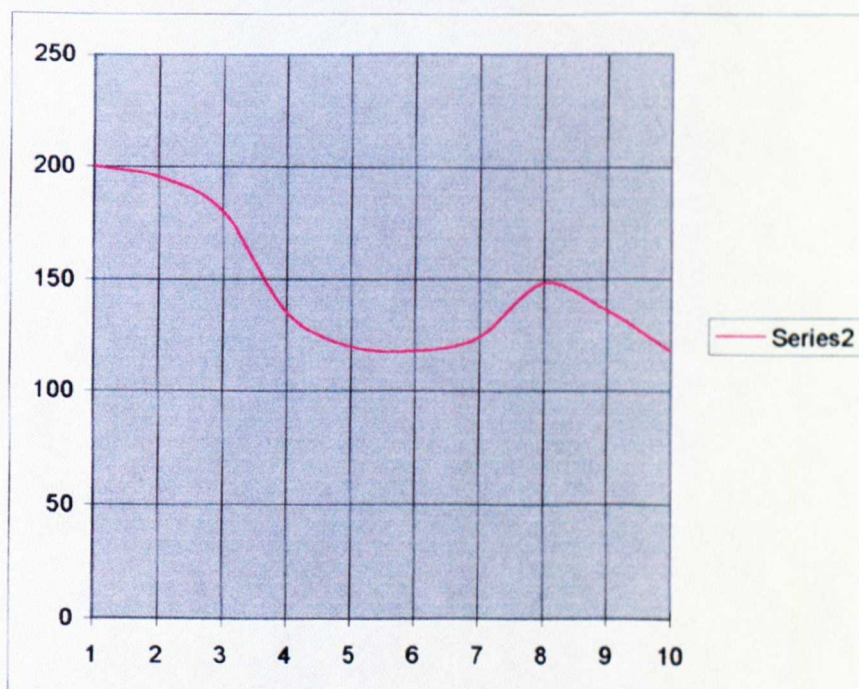
Developing Thinking Skills

Unit P1: Thinking Graphs

Graphs are often used to show information. You can use bar charts, line graphs, pie charts and other types of graphs to show information. Usually, you are asked a simple question concerning the graph and you 'read off' the information from the graph to answer the question.

'Thinking Graphs' are different in the way that they work because you have to match statements to places on the graph and explain why you put that statement at that place. The answer that you give involves you thinking about *why* you think the statement fits at place on the graph along with your own personal explanation.

Look at the following graph and put the statements below where you think they should go. The graph shows how the height of a bungee jumper changes over the 10 seconds of her bungee jump.



Thinking Graph Statements:

1. Rebecca is really scared!
2. "I'm going to fast!" Rebecca screams.
3. "Thank heavens that's over!" Rebecca screams.
4. Rebecca has stopped moving.
5. People on the ground can see Rebecca moving back up.
6. The Earth seems really close to Rebecca.
7. "The bungee is starting to pull me back up!" Rebecca wails
8. Rebecca feels ill!

Appendix 21

Introductory mnemonics materials used at GCSE and AS level.

Developing Thinking Skills

Mnemonics

A mnemonic is an easy way to remember something more difficult. We look at the words and we take each of the first letters and use them to remember a sequence. For example, the colours of the rainbow are red, orange, yellow, green, blue, indigo, velvet. By taking the first letters of each colour we get Roy G. Biv, which is a name that we can use to remember the correct order of the colours. Or... we can turn the colours into another saying such as 'Richard of York gave battle in vain' which also has the same sequence of letters.

What about the order of the planets in the solar system?

The order of the planets, outwards from the sun, is: **Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto.**

You can remember this sequence by saying:

"My very earthly mother just served us nine pizzas" because the first letter in each word is in the same order as the first letter in the order of the planets in the solar system.

Make up your own Mnemonics to help remember the following:

1. The order of the planets.
2. The colours in the rainbow.
3. The senses.
4. The life processes.
5. The female reproductive system.
6. The male reproductive system.
7. The types of renewable energy resources.
8. The types of non-renewable energy resources.
9. The stages in the production of electricity in a power station.
10. The types of energy that there are.
11. The members of the electromagnetic spectrum.

Developing Thinking Skills

Mnemonics

Write your mnemonics in the table below. Try to make your mnemonic memorable by using humour.

[illegible]

Appendix 22

Introductory VAKi materials used at GCSE.

Developing Thinking Skills

VAKi

VAKi stands for Visual, Auditory and Kinaesthetic.

Learning episodes using VAKi involve seeing, hearing and acting out the work. As an example, students who are studying the solar system could be made to watch video material, listen to the teacher and then act out a scale model of the solar system by asking them to take up positions in the playground. This strategy would help them recognise the distance between the outer planets in comparison to the distance between the inner planets. Another opportunity for using VAKi is for the teaching of key terms in electrical circuits. Students can represent electric charge and by moving around the classroom they can demonstrate current as the movement of charge. Electrical energy, which is carried by charge, can be represented as smarties which are fed to pupils pretending to be lamps or buzzers. Potential difference can be represented by a static child at the front of the class who gives smarties to charge pupils as they move through the cell. The potential difference gives the charge a push as it returns back into the circuit.

Other opportunities for the use of VAKi include:

1. Showing how electromagnets work.
2. Showing how osmosis works.
3. Explaining conduction of thermal energy.
4. Demonstrating chemical equilibrium.
5. Demonstrating Brownian motion and diffusion.
6. Demonstrating refraction of light.
7. Showing how solids, liquids and gases behave.
8. Comparing speeds of various types of movement.
9. Demonstrating centre of mass and stability.
10. Illustrating desirable conditions for photosynthesis.

Appendix 23

Introductory KWL material used at GCSE and AS level.

Developing Thinking Skills

Unit P2: K.W.L.

K.W.L. stands for 'Know, Want to know, Learned'. When learning something new, you can use this strategy to help you keep track of what you already know, what you want to know and then, after the lesson, what you have learned that you didn't know before.

This strategy is very useful when watching video material in class. Suppose you are going to watch a video about the solar system. You should never just watch the video without attempting to make notes. However, if you make too many notes you might miss something of interest or something important. By using KWL, you can write down a few facts about the solar system before watching the video. You can also write down a few things that you want to learn from the video. Whilst watching the video you can add new information in the 'L' column as this is the new stuff that you have just learned. It's a great way to learn and a great way to increase your confidence about your own learning.

Here is an example of how to lay out your page when doing a KWL exercise:

K	W	L
<ul style="list-style-type: none">I know the solar system has nine planets		
<ul style="list-style-type: none">I know the planets orbit the sun		
<ul style="list-style-type: none">I know that Earth has one moon		
<ul style="list-style-type: none">I know that Neil Armstrong was the first man on the moon		
<ul style="list-style-type: none">I know that there are asteroids between Mars and Jupiter		

The 'K' column is the first to be filled in because that is the information that is already known, followed by the 'W' column. At the end of the learning episode the 'L' column is filled in so your final KWL sheet might look like this:

K	W	L
<ul style="list-style-type: none"> • I know the solar system has nine planets 		
<ul style="list-style-type: none"> • I know the planets orbit the sun 		
<ul style="list-style-type: none"> • I know that Earth has one moon 		
<ul style="list-style-type: none"> • I know that Neil Armstrong was the first man on the moon 		
<ul style="list-style-type: none"> • I know that there are asteroids between Mars and Jupiter 		

Developing Thinking Skills

K.W.L. Blank Grid

[illegible]

Appendix 24

Metacognitive question grids and associated metacognitive material.

Developing Thinking Skills

Metacognition

Metacognition means ‘thinking about your thinking’. Before attempting to answer a problem, it is best if students look at the problem and decide which aspects of the problem need the most attention. Students should be encouraged to be ‘reflective’ learners, returning to the problem on a number of occasions, making comparisons between prior and current knowledge and being aware of any difficulties that they might encounter in a learning episode.

During the answering of a problem, such as an exam question, it is a good idea to monitor progress. For example, is the student answering the question as it has been written? How many marks is the question worth? Is the student writing enough? Is the student writing too much? Does the student fully understand what she has written? Is the student using the correct terms and language? Does the student possess enough knowledge to answer the question? If not, what should she do to increase or improve her knowledge?

After answering the problem, the student needs to ‘evaluate’ her learning and try to learn from it. The student who progresses to a stage of deeper understanding should be able to do the following:

- Identify the use and purpose of the learned material
- Handle learned material in a different manner
- Explore potential use of learned material under different circumstances.

The student should also exhibit the following skills:

- Greater ability to utilise learned material in order to meet long term goals
- Greater confidence in the learned material leading to less chance of the student ‘regressing’ back to a previous, less developed stage of understanding.

The resources provided for the teaching and learning of metacognitive skills are:

1. Metacognition question sheets
2. Metacognition feedback sheets
3. Certainty of Response Index (CRI) sheets.

Other possible questions for metacognitive instruction:

1. Before this lesson, what was your opinion about the topic?
2. Have your views about this topic changed? If so, why?
3. Explain to your friend how you solved a problem you were given.
4. Give two reasons why the material you have learned is useful.
5. Give two reasons why you think you need to learn this topic.
6. Write down three things that you have learned in this lesson and any points which are still not clear.
7. If you were given a question to answer on this topic, how many marks do you think you would get out of ten?

Developing Thinking Skills

Metacognition Question Sheet

A question has been placed in the box below and it is worth 5 marks. Think about what the question involves and use that to write the mark scheme that you feel best fits the question.

Question:

Write your thinking here:

Write down you mark scheme here. Each bullet point is one mark.

◆

◆

◆

◆

◆

Developing Thinking Skills

Metacognition feedback sheet

Fill in the sheet below to help you learn more about your learning.

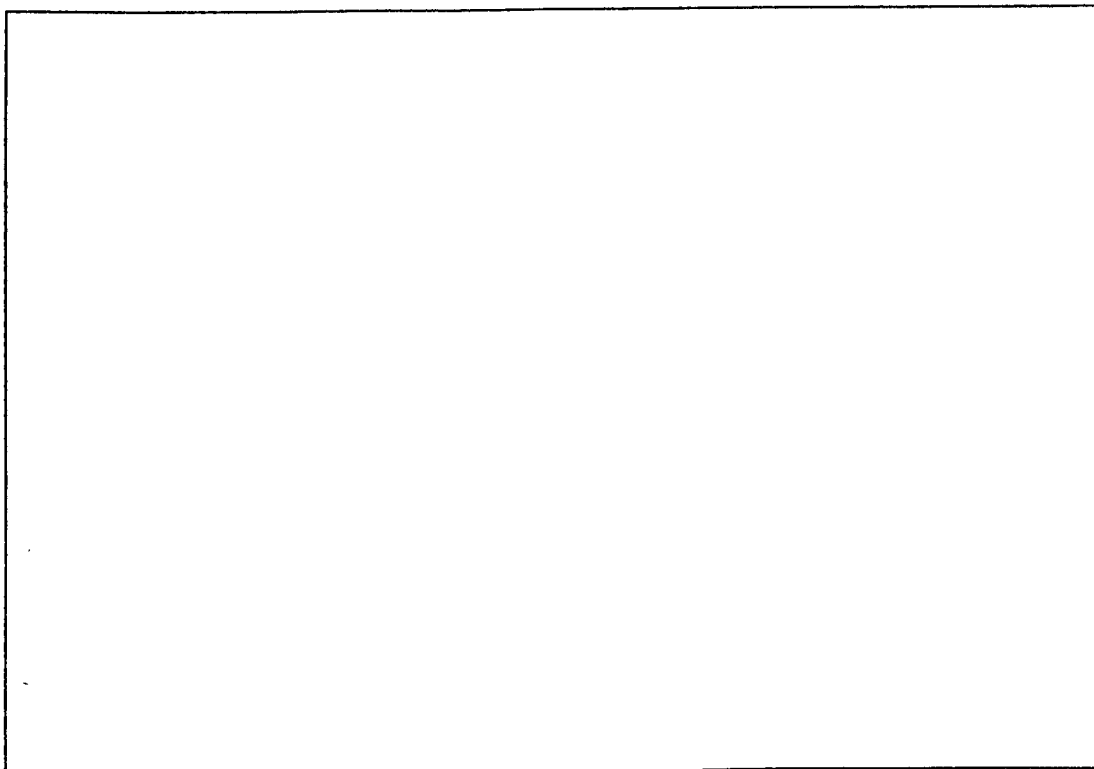
What did you know about this topic before the learning episode?

What have you learned about this topic since the learning episode?

What will you do now to improve on what you have learned?

Name _____ Group _____

This question must not be worth more than _____ marks.



Fill in your mark scheme below:

1.	
2.	
3.	
4.	
5.	

Appendix 25

Exemplar materials produced by students to assist research.

Physics Vocabulary Questionnaire Years 10, 11, 12, 13

The following words have meanings in common, everyday usage, but they also have meaning in Physics. See how well you can fill in the two columns, one of which contains the everyday meaning and the other one that contains the physics meaning. The first one has been done for you:

Term:	Everyday usage	Physics usage
1. Current	happening at the moment	the flow of electric charge
2. Conductor	Men in charge of band	Something that allows flow of charge.
3. Concentration	Strength of orange juice.	No of molar per unit vol.
4. Power	Strength.	Power = current \times voltage.
5. Induction	Induction day.	when a current is created.
6. Moment	Now	A turning force.
7. Conservation	when 2 dyslexic people talk.	conservation of energy energy is neither created or destroyed.

8. Resistance is futile,

$$R = \frac{V}{I}$$

9. Charge TO move toward something at pace.

$$Q = It$$

10. Mass Amount of something

$$m = \text{weight} \times g$$

11. Friction Tension
a between John + flowers.

Force that opposes motion.

12. Solution The Answer.

Liquid made up of solute + solvent

13. Wave A gesture made
by R. Johnson towards
other road users.

A method of transferring energy without causing the particles to move horizontally very much.

14. Work Mr Mead's chemistry lessons are full of it.

$$W = Fd$$

15. Pressure Stress.

$$P = \frac{F}{A}$$

16. Cell where Charles Bronson is in.

Single unit
A ~~cell~~ or a battery.

17. Potential Ability to achieve a high standard if body and mind are adequately used.

$$V = IR$$

18. Volume

level of noise (should be low when listening to AK's albums which are really poor).

$$V = \frac{Q}{M}$$

Physics Vocabulary Questionnaire Years 10, 11, 12, 13

The following words have meanings in common, everyday usage, but they also have meaning in Physics. See how well you can fill in the two columns, one of which contains the everyday meaning and the other one that contains the physics meaning. The first one has been done for you:

Term:	Everyday usage	Physics usage
1. Current	happening at the moment	the flow of electric charge
2. Conductor	- person who collects fares on trams & buses - leader of an orchestra	A device which allows the flow of electricity or heat
3. Concentration	To think intensely about an idea	The amount of a substance contained within a solution or mixture
4. Power	Ability to do something Ability to influence people Authority Strength	The rate at which work is done or sometimes the rate at which displacement energy is transferred *
5. Induction	To introduce a new person to an organisation.	Using electricity to create a magnetic field and magnetism create a current with no contact between the 2 bodies. moment = force \times perpendicular distance to a point
6. Moment	- A short amount of time - A certain point in time	The turning effect of a force around a point / pivot
7. Conservation	To save or protect	when the total value of a quantity remains constant e.g. momentum energy

* Strength of a lens

8. Resistance To oppose e.g. an idea or law

After exposure to a

disease to not become ill with that

9. Charge

disease due to previous exposure

To ask for money for goods etc

Accuse + arrest Someone for an offence

To race towards a person/object

10. Mass

A large number of objects / people

Service of worship in a church

a body with no definite shape

11. Friction

Feeling

the ~~friction~~ between two

people who disagree

12. Solution

Answer to a problem

or question

13. Wave

move a hand to and fro in
greeting

waves in the sea caused by
the wind

14. Work

Job

To study a subject in order
to gain qualifications (i.e. Schoolwork)

15. Pressure

To perform a task

To force someone to do
something they are reluctant to do

16. Cell

The fundamental unit in all
organisms consisting of a cytoplasm + nucleus

A small room in which a prisoner is locked
up.

17. Potential

The possibility that something
may happen in the future

Opportunity to develop.

18. Volume

How loud a noise is

A book that forms part of a
series

The opposition of the
flow of current.

Property of m
organic factories that allow
electrostatic forces to act
charges are +ve or -ve on.

The amount of matter
that is contained within
a body

Opposition to movement
created when one object
meets another.

A liquid mixture in
which the particles are even
distributed.

A wave transports energy
from one point to another by
passing vibrations from one
molecule to another.

When a force moves an
object that is the direction
in which the force is applied
Overcoming a resistive force.

The force per unit area,
exerted by an object,
solution, or gas.

A store of chemical
potential energy - also
known as a battery.

The stored ability to
do work.

The amount of space
occupied by a substance
either as a solid or
mixed in a solution.

Potential question

lens formula

f no calculations

ray diagram construction - qualitative.

1. Asim needs to take a photo of some Aliens in his back garden. It is a very dark night and so Asim stupidly decides to use a fno of $f/16$ and shutter speed of $1/500$ s - The sort of set up used to take pictures of the sun at a distance of 3cm. After developing the photo Asim's dad laughs + says "Asim you silly boy the aperture area of your camera needs to be increased by a factor of 128"

a. What new fno value is Asim's dad suggesting Asim use.

b. Asim's dad then goes on to say to capture the alien on photo he needs to let 8000 times more light in* using the new fno. What is the new shutter speed?

c. Asim follows his dad's advice but this time the stupid idiot covers $3/8$ of the aperture with his finger. Given that the light enters the aperture uniformly what would the new shutter speed be given the fno remains $f/1.4$? to let the same amount of light in.

$$fno^2 \propto \frac{1}{A} \quad A \uparrow 128 \quad (1) \\ fno^2 \downarrow 128$$

$$\frac{16^2}{128} = 2 = \text{new } fno^2 \quad (1)$$

$$fno = \sqrt{2} \quad (1)$$

$$\frac{1}{\sqrt{2}^2} \cdot T = \left(\frac{1}{16^2} \cdot \frac{1}{500} \right) 8000 \quad (1)$$

$$T = \frac{1}{8} \text{ secs} \quad (1)$$

$$A \propto \frac{1}{fno} \quad \therefore \frac{5}{8} A = \frac{5}{8 fno} \quad (1)$$

$$\left(\frac{1}{16^2} \cdot \frac{1}{500} \right) 8000 = \frac{5}{8} \cdot \frac{1}{\sqrt{2}^2} \cdot T \quad (2)$$

$$T = \frac{1}{5} \text{ secs} \quad (1)$$

a2 If it is so that $A = \frac{\pi \times 10^{-2}}{(f_{no})^2}$

and the aperture is a circle
find the radius of the circle
if $f_{no} = f/2$

b. If r is halved what is
the new f/no .

$$A = \frac{\pi \times 10^{-2}}{(f_{no})^2} \quad (1)$$

$$\pi r^2 = \frac{\pi \times 10^{-2}}{2^2} \quad (1)$$

$$r = \sqrt{2.5 \times 10^{-3}}$$

$$r = 0.05 \text{ m} \quad (1)$$

$$\pi (0.05 \div 2)^2 = \frac{\pi \times 10^{-2}}{f_{no}^2} \quad (1)$$

$$0.0625 = \frac{1}{f_{no}^2}$$

$$f_{no} = 4 \quad (1)$$

$$\left. \begin{array}{l} f_{no} \propto \frac{1}{d} \\ \frac{d}{2} \Rightarrow f_{no} \times 2 \end{array} \right\} \begin{array}{l} \text{or} \\ (2) \end{array}$$

Life cycle of a star

What makes it difficult

The problem with understanding this concept is that it is macrophenomenon. It is not an everyday occurrence, it takes place over many millions of years and because of this there are no actual ~~one~~ visual resources* that can be used e.g. videos. At G.C.S.E. level there is no obvious evidence to support the life cycle of a star as the ~~the~~ evidence that disprove them is beyond the scope of GCSE! \therefore there is no obvious evidence it is hard to accept and \therefore hard to learn.

Some of the terms used although not difficult are often hard to remember and the order in which they occur may become confused especially in an exam situation.

Making it Easier

The use of a flow chart which would use keywords and key points would make it clearer which information is the most important.

Pictures to accompany the chart could also be used. It might be more helpful if the pictures were drawn by hand as the pupil might find remembering the pictures easier especially if they have drawn them.

Analogy - As old giants age they shrivel to white dwarfs, this could be compared to humans shrinking as they age.

Boyle's law

What makes it difficult

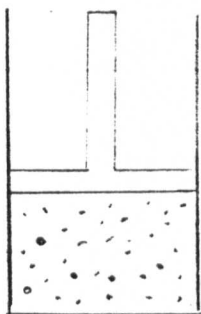
The problem with Boyle's law is the use of maths and the formula $p_1 V_1 = p_2 V_2$ and the fact that pV is a constant value. It can be thought that it is the values for p and V do not change rather than pV . It is difficult for people to visualize that pV is constant \therefore the values for p and V have changed.

Another problem is that the gas ^{individual} molecules can't be seen and so the forces the molecules are exerting and ~~also~~ \therefore the overall pressure can't be seen.

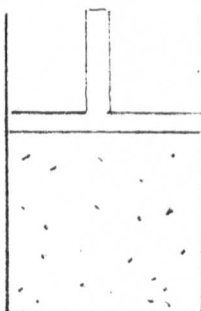
Making it easier

Demonstrate using Boyle's law apparatus.

Rearrange pV to show that p and V are inversely proportional to each other.



Small vol \longrightarrow molecules close together \longrightarrow exert a great pressure



Larger vol \longrightarrow molecules further apart \longrightarrow exert a small pressure

Emphasise the fact that the n° of molecules remains the same.

analogy - Commuters on a train

If 100 commuters get on a train one day, and this train only has two carriages then the pressure they exert on each other is high (because they are squashed together, they are exerting quite a large force over a small area) and the volume is quite small.

If the same 100 commuters get on a train, this time the train has four carriages then the volume will have doubled and the pressure will have halved \therefore the same force is exerted over double the area.

To show $PV = \text{a constant}$

$$P_1 = P_2 V_2$$

$$P_2 V_2 = \frac{1}{2} P_1 2V_1 = P_1 V_1$$

Practise firstly with all values given to prove PV is a constant, then move onto using $P_1 V_1 = P_2 V_2$ to calculate an unknown value

Use of molecular models as containers of different volumes to give an approximate representation.

Novice

- Puts numbers into formulae - doesn't think.
- Don't hear alarm bells when answers are strange.
- Starts immediately + doesn't think fully about question
- Doesn't understand physics + just thinks of equations
- Panics when a question comes up they haven't practiced
- Can't apply knowledge to practical situations

Expert

Thinks of physics involved
+ finds suitable equations.

Thinks if answers are sensible or not.

Understands the physics involved

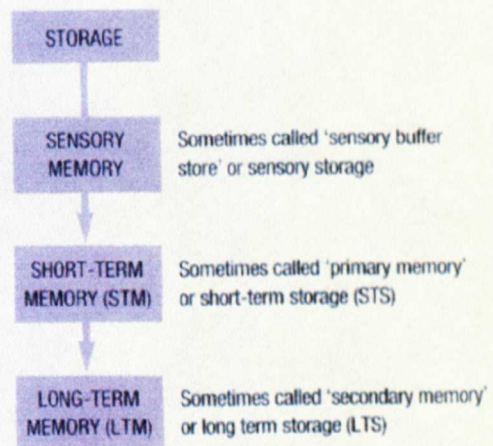
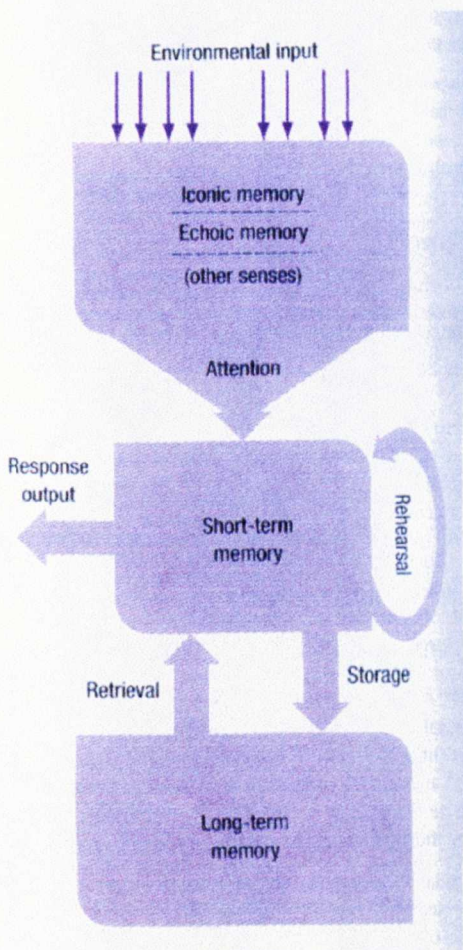
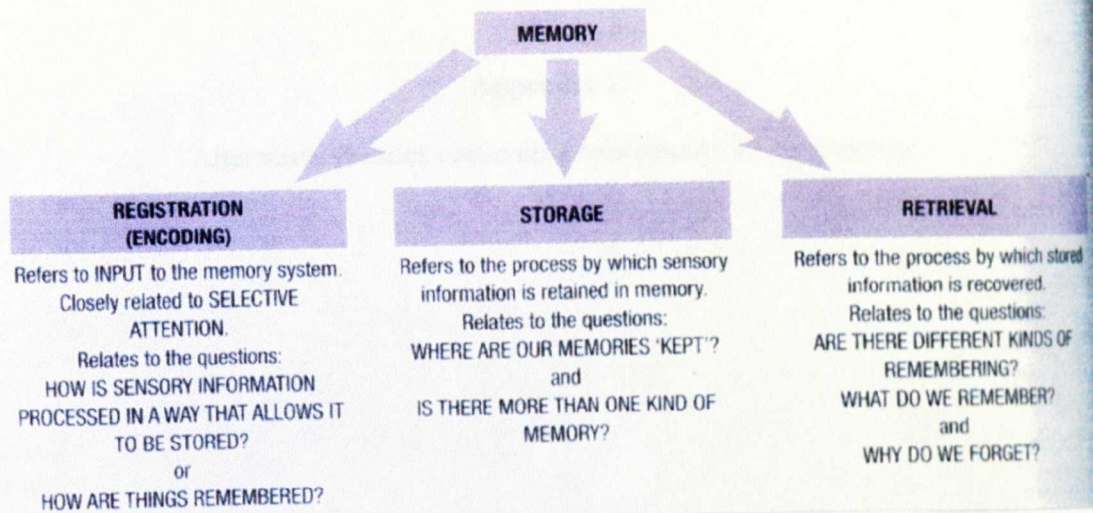
Is able to cope with new types of questions - thinks about physics.

Is able to apply knowledge to practical situations
e.g. questions about real things.

Puts thought into questions
- doesn't just drive in + try and get them done.

Appendix 26

Multi-store model representation of human memory.



Appendix 27

Alternative theories concerning conceptual change learning.

Alternative theories and strategies concerning conceptual change.

Theory / Strategy	Author(s).	Main points of theory.
Replacement Theory (Theory)	Vosniadou (1992,1994)	Treats process as one of replacing existing mental structures with others. Involves enrichment and revision.
Multiple Representations (Theory)	Caravito and Hallden (1994)	We have a range of theories about the world. With experience, one replaces another.
Refutational Text (Strategy)	Guzzetti (1990)	Uses misconceptions to allow a superior, alternative model to replace an old, less accurate one.
Activating Prior Learning (Strategy)	Guzzetti (1990)	Uses prior knowledge to resurrect a misconception for refuting.
Peer Group Discussion (Strategy)	Lonning (1993)	Uses well-organised group work sessions to develop new knowledge. Referred to often as co-operative learning.
Analogy and Example (Strategy)	Brown (1992)	Uses analogy and example to help bridge learning from the 'anchor' to the 'target'.
Demonstration (Strategy)	Guzzetti (1990)	As its name suggests, using a demonstration to display the inadequacy of a view that is a misconception.
Displacement (Strategy)	Guzzetti et al. (1993) Newton (2000)	Strategies that allow strongly resistant misconceptions to co-exist with the new or desired conception. A number of combined strategies such as analogy and refutational text can help in the displacement of such misconceptions.
Prediction (Strategy) Forced Prediction (Strategy)	Hameed, Saxana (1993/1992) Newton (2000)	Predictions, based on misconceptions, can lead to situations where misconceptions are shown to be incorrect. Hopefully, the new idea will replace the previously held misconception. Involves conceptual conflict and can use events not in the real world such as via ICT simulations. Forced prediction is a type of focused question where students are obliged to connect or explain initial and final conditions via a causal link. The student is forced to observe, process and analyse information in a way that patterns and relationships can be noticed and subsequently commented on.

Appendix 28

Raw data for year 10 experimental and control groups involved in the research with corresponding t-test and effect size statistics.

Year 10 Raw Data for Physics Paper

	C1	C2	C3
	experimental	control	pooled
1	58	54	58
2	94	58	94
3	67	67	67
4	87	34	87
5	45	56	45
6	67	78	67
7	88	78	88
8	76	34	76
9	56	38	56
10	39	56	39
11	78	47	78
12	70	89	70
13	59	45	59
14	71	53	71
15	89	39	89
16	78	70	78
17		56	54
18		57	58
19		58	67
20		48	34
21		57	56
22		68	78
23			78
24			34
25			38
26			56
27			47
28			89
29			45
30			53
31			39
32			70
33			56
34			57
35			58
36			48
37			57
38			68

Two Sample T-Test and Confidence Interval

Two sample T for experimental vs control

	N	Mean	StDev	SE Mean
experime	16	70.1	15.9	4.0
control	22	56.4	14.5	3.1

95% CI for mu experime - mu control: (3.5, 24.0)
T-Test mu experime = mu control (vs not =): T = 2.74

P = 0.010 DF = 30

Column Standard Deviation

Standard deviation of pooled = 16.373

Effect size = (experimental mean - control mean) / pooled standard deviation

Effect size = (70.1% - 56.4%) / 16.373

Effect size = 13.7 / 16.373

Effect size = 0.84

Year 10 Raw Data for Electricity and Magnetism Test.

	C1	C2	C3
	control	experimental	pooled
1	54	78	54
2	67	87	67
3	54	96	54
4	45	58	45
5	57	74	57
6	48	79	48
7	79	59	79
8	65	78	65
9	82	69	82
10	46	84	46
11	58	87	58
12	64	79	64
13	37	68	37
14	54	69	54
15	55	59	55
16	47	76	47
17	48		48
18	56		56
19	47		47
20	54		54
21	60		60
22	55		55
23			78
24			87
25			96
26			58
27			74
28			79
29			59
30			78
31			69
32			84
33			87
34			79
35			68
36			69
37			59
38			76

Two Sample T-Test and Confidence Interval

Two sample T for experimental vs control

	N	Mean	StDev	SE Mean
experime	16	75.0	10.9	2.7
control	22	56.0	10.7	2.3

95% CI for mu experime - mu control: (11.8, 26.2)
T-Test mu experime = mu control (vs not =): T = 5.35

P = 0.0000 DF = 32

Column Standard Deviation

Standard deviation of pooled = 14.247

Effect size = (experimental mean - control mean) / pooled standard deviation

Effect size = (75% - 56%) / 14.247

Effect size = (19%) / 14.247

Effect size = 1.33

Appendix 29

Raw data for year 11 experimental and control groups involved in the research with corresponding t-test and effect size statistics.

Year 11 Raw Data for F tier Paper

	C1	C2	C3	C4
	candidate	control scores	experiment scores	pooled scores
1		70	74	74
2		68	72	72
3		59	68	68
4		80	63	63
5		47	70	70
6		76	84	84
7		78	85	85
8		73	87	87
9		59	78	78
10		70	62	62
11		52	66	66
12		67	59	59
13		58	68	68
14		39	70	70
15		48	43	43
16		69	67	67
17		72	59	59
18		68	52	52
19		85	69	69
20		78	85	85
21		86	79	79
22		57	62	62
23		82	88	88
24				70
25				68
26				59
27				80
28				47
29				76
30				78
31				73
32				59
33				70
34				52
35				67
36				58
37				39
38				48
39				69
40				72
41				68
42				85
43				78
44				86
45				57
46				82

Paired T-Test

95% CI for mean difference: (-2.57, 8.57)

T-Test of mean difference = 0 (vs not = 0): T-Value = 1.12 P-Value = 0.276

Year 11 Raw Data for H tier Paper

	C1	C2	C3
	experimental	control	pooled data
1	56	47	47
2	64	41	41
3	48	53	53
4	70	58	58
5	42	36	36
6	56	47	47
7	58	49	49
8	54	45	45
9	59	52	52
10	68	52	52
11	53	42	42
12	45	42	42
13	82	74	74
14	30	20	20
15	49	54	54
16	67	41	41
17	46	48	48
18	46	39	39
19	71	42	42
20	62	40	40
21	50	45	45
22	56	45	45
23	56	70	70
24			56
25			64
26			48
27			70
28			42
29			56
30			58
31			54
32			59
33			68
34			53
35			45
36			82
37			30
38			49
39			67
40			46
41			46
42			71
43			62
44			50
45			56
46			56

Column Mean

Mean of control = 47.043

Column Mean

Mean of experimental = 56.000

Paired T-Test and Confidence Interval

Paired T for experimental - control

	N	Mean	StDev	SE Mean
experiment	23	56.00	11.34	2.36
control	23	47.04	10.96	2.28
Difference	23	8.96	10.07	2.10

95% CI for mean difference: (4.60, 13.31)

T-Test of mean difference = 0 (vs not = 0): T-Value = 4.26

P-Value = 0.000

T Confidence Intervals

Variable	N	Mean	StDev	SE Mean	95.0 % CI
experime	23	56.00	11.34	2.36	(51.10, 60.90)
control	23	47.04	10.96	2.28	(42.31, 51.78)

Column Standard Deviation

Standard deviation of experimental = 11.342

Column Standard Deviation

Standard deviation of pooled experimental and control= 11.920

Column Standard Deviation

Standard deviation of experimental = 11.920

effect size = $(56 - 47) / 11.920 = 0.755$

Variance : $\sigma^2 = \frac{\sum (x - \bar{x})^2}{n}$; standard deviation = $\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{n}}$

Effect size :

$$\frac{M_E - M_C}{\sigma_p}$$

where : M_E = experimental mean

M_C = control mean

σ_p = pooled S. dev.

candidate no.	control	experimental	$(x - \bar{x})$		$(x - \bar{x})^2$	
1	70	74	3	4	9	16
2	68	72	1	2	1	4
3	59	68	-8	-2	64	4
4	80	63	13	-7	169	49
5	47	70	-20	0	400	0
6	76	84	9	14	81	196
7	78	85	11	15	121	225
8	73	87	6	17	36	289
9	59	78	-8	8	64	64
10	70	62	3	-8	9	64
11	52	66	-15	-4	225	16
12	67	59	0	-11	0	121
13	58	68	-9	-2	81	4
14	39	70	-28	0	784	0
15	48	43	-19	-27	361	729
16	69	67	2	-3	4	9
17	72	59	5	-11	25	121
18	68	52	1	-18	1	324
19	85	69	18	-1	324	1
20	78	85	11	15	121	225
21	86	79	19	9	361	81
22	57	62	-10	-8	100	64
23	82	88	15	18	225	324
	1541	1610			3566	2930

* these values calculated for Year 11, Fisher for Table 7.5 p. 153

$$\text{Effect size} = \frac{\mu_E - \mu_C}{\sigma_p}$$

$$\mu_E = 70\%$$

$$\mu_C = 67\%$$

$$\therefore \Delta\mu = \mu_E - \mu_C = \underline{\underline{3\%}}$$

$$\text{Effect size} = \frac{\Delta\mu}{\sigma_p}$$

$$\sigma_p^2 = \frac{\sum (x - \bar{x})_E^2 + \sum (x - \bar{x})_C^2}{[n_C + n_E]} = \frac{3566 + 2930}{46}$$

$$\therefore \sigma_p^2 = 141.2$$

$$\text{hence, } \sigma_p = \sqrt{141.2} = \underline{\underline{11.9}}$$

$$\therefore \text{Effect size} = \frac{3\%}{11.9} = \underline{\underline{0.25}}$$

Since $0.25 < 0.4$, there is no real evidence to suggest that there is a significant difference in performance between the two groups in the F-tier examination.

$$\begin{array}{lcl} \text{minitab : } & T\text{-value} = -1.12 & P\text{-value} = 0.276 \\ & \text{effect size} = \frac{3}{12.11} = \underline{\underline{0.25}} & \end{array} \left. \vphantom{\begin{array}{lcl} \text{minitab : } & T\text{-value} = -1.12 & P\text{-value} = 0.276 \\ & \text{effect size} = \frac{3}{12.11} = \underline{\underline{0.25}} & \end{array}} \right\} \text{F-tier.}$$

$$\begin{array}{lcl} & \text{standard deviation} = 11.920 & ; \text{ effect size} = \underline{\underline{0.76}} \\ & T\text{-value} = 4.26 & P\text{-value} = 0.000 \end{array} \left. \vphantom{\begin{array}{lcl} & \text{standard deviation} = 11.920 & ; \text{ effect size} = \underline{\underline{0.76}} \\ & T\text{-value} = 4.26 & P\text{-value} = 0.000 \end{array}} \right\} \text{H-tier}$$

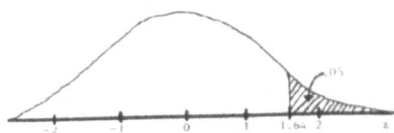
Appendix 30

Tables needed for t-test calculations.

TABLE C.2
Critical Values of z

The table shows the "level of significance" associated with a selection of z-scores. Read the level from the top line of the table for a two tail test or from the bottom line for a one tail test.

Illustration:

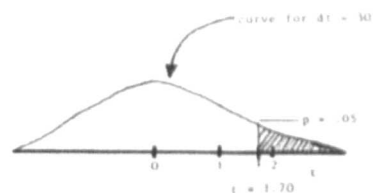


If $z = 1.64$ the level of significance using a two tail test was .10. For a one tail test the level of significance was .05.

Level for two tail test:	.50	.20	.10	.05	.02	.01	.001
z	.67	1.28	1.64	1.96	2.33	2.58	3.29
Level for one tail test:	.25	.10	.05	.025	.01	.005	.0005

TABLE C.3
Critical Values of t

Illustration:



Level for two tail test:	.50	.20	.10	.05	.02	.01	.001
df							
1	1.00	3.07	6.31	12.70	31.82	63.65	636.67
2	.81	1.88	2.92	4.30	6.96	9.92	11.99
3	.76	1.63	2.35	3.18	4.54	5.84	12.92
4	.74	1.53	2.13	2.77	3.74	4.60	8.61
5	.72	1.47	2.01	2.57	3.36	4.03	6.86
6	.71	1.44	1.94	2.44	3.14	3.70	5.95
7	.71	1.41	1.89	2.36	2.99	3.49	5.40
8	.70	1.39	1.86	2.30	2.89	3.35	5.04
9	.70	1.38	1.83	2.26	2.82	3.25	4.78
10	.70	1.37	1.81	2.22	2.76	3.16	4.58
11	.69	1.36	1.79	2.20	2.71	3.10	4.43
12	.69	1.35	1.78	2.17	2.68	3.05	4.31
13	.69	1.35	1.77	2.16	2.65	3.01	4.22
14	.69	1.34	1.76	2.14	2.62	2.97	4.14
15	.69	1.34	1.75	2.13	2.60	2.94	4.07
16	.69	1.33	1.74	2.12	2.58	2.92	4.01
17	.68	1.33	1.74	2.11	2.56	2.89	3.96
18	.68	1.33	1.73	2.10	2.55	2.87	3.92
19	.68	1.32	1.72	2.09	2.53	2.86	3.88
20	.68	1.32	1.72	2.08	2.52	2.84	3.85
21	.68	1.32	1.72	2.08	2.51	2.83	3.81
22	.68	1.32	1.71	2.07	2.50	2.81	3.79
23	.68	1.31	1.71	2.06	2.50	2.80	3.76
24	.68	1.31	1.71	2.06	2.49	2.79	3.74
25	.68	1.31	1.70	2.06	2.48	2.78	3.72
26	.68	1.31	1.70	2.05	2.47	2.77	3.70
27	.68	1.31	1.70	2.05	2.47	2.77	3.69
28	.68	1.31	1.70	2.04	2.46	2.76	3.67
29	.68	1.31	1.69	2.04	2.46	2.75	3.65
30	.68	1.31	1.69	2.04	2.45	2.75	3.64
40	.68	1.30	1.68	2.02	2.42	2.70	3.55
60	.67	1.29	1.67	2.00	2.39	2.66	3.46
120	.67	1.28	1.65	1.98	2.35	2.61	3.37
	.67	1.28	1.64	1.96	2.32	2.57	3.29

120: For df larger than 200 treat t as z.

Level for one tail test:	.25	.10	.05	.025	.01	.005	.0005
--------------------------	-----	-----	-----	------	-----	------	-------

Note: For independent t-test, $df = n_1 + n_2 - 2$

For paired data t-test, $df = N - 1$ where $N =$ no. of pairs

Appendix 31

Standardisation proforma used during year 10 teaching period.

Standardisation Proforma for Lessons involving experimental and control groups in years 10 and 11.

Year Group:

Content:

Experimental strategies:

Control strategies:

Resources:

Evaluation of parallel lessons:

Experimental teacher signature.

Control teacher signature.

Standardisation Proforma for Lessons involving experimental and control groups in years 10 and 11.

Year Group: 10 (whole week) Tues/Thurs

Content: Electrical circuits: current, voltage, energy and charge.

Experimental strategies:

- VAK - Smarties expt.
- Use of whiteboard for circuit diagrams/Notes.
- building circuits via pole bridging.
- short test on key words.

Control strategies:

- bookwork.
- use of whiteboard for notes/notes.
- building circuits (without pole bridging.)

Resources:

electrical circuits equipment, whiteboard, GCSE kits (for both groups), Smarties, VAK* cards, pole bridging notes (* - experimental group only). No H/W set.

Evaluation of parallel lessons:

lessons observed. Appropriate use of strategies observed in experimental and control groups.

Experimental teacher signature.

Michael Rowe

Control teacher signature.

John